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TOPSIDE INTERMODULATION INTERFERENCE ABOARD USS MOUNT WHITNEY (LCC 20), USS BLUE RIDGE (LCC 19), AND USS IWO JIMA (LPH 2)

Applies the concepts of very-high-order IM interference for the first time to real shipboard environments.

G. C. Salisbury 27 December 1972

NAVAL ELECTRONICS LABORATORY CENTER
San Diego, California 92152

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PREFACE

The results of the topside interference measurements reported in this document have been previously promulgated by NELC in the form of preliminary letter reports. Distribution was limited to those commands believed to be immediately concerned. It is now thought, however, that the results are of wider interest. Hence, this issuance is made.

The work was performed under O&MN ~~NAVSEC~~ (NELC B169) by members of the Radio Technology Division from March 1971 to November 1971. In addition to the author, W. M. Chase, L. S. Hansen, and D. E. Porciuncula participated. This document was approved for publication 27 December 1972.

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SECTION 1

INTRODUCTION

1.1 SCOPE OF DOCUMENT

This document presents the results of measurements of intermodulation (IM) interference taken aboard USS MOUNT WHITNEY (LCC 20), USS BLUE RIDGE (LCC 19), and USS IWO JIMA (LPH 2). In addition, the results of laboratory tests of connectors that were interference sources aboard BLUE RIDGE are reported. Details of the measurement instrumentation, procedures, and results are contained in sections 2 through 6. These sections are outlined below.

Section 2 gives measurement results obtained aboard MOUNT WHITNEY, and compares them with results obtained aboard USS FOX (DLG 33). MOUNT WHITNEY was found to have considerably lower interference levels than FOX. FOX had previously been considered to have the lowest topside-generated rfi levels among active Fleet warships. Her good performance resulted from extensive topside rfi control measures (nonmetallic topside fixtures plus MIL-STD-1310B bonding) installed in an earlier program. MOUNT WHITNEY, on the other hand, was originally designed and built for low topside levels.

Section 3 presents hf and vhf results obtained aboard BLUE RIDGE, and compares them with results obtained aboard MOUNT WHITNEY. Topside levels were determined to be higher than those obtained aboard MOUNT WHITNEY but lower than those obtained aboard FOX, and it is not believed topside-generated interference constitutes a high probability threat to communications aboard BLUE RIDGE.

Certain aspects of the BLUE RIDGE data indicated that strong sources of intermodulation interference are contained in a broadband transmitting antenna system. This problem needs further investigation to devise corrective measures. Also, both amphibious command ships, MOUNT WHITNEY and BLUE RIDGE, appeared subject to a gradual increase in topside-generated IM levels because of deterioration of topside bonding. Maintenance costs could be reduced by a limited program to replace certain topside items with glass-reinforced plastic parts.

Section 4 gives results of uhf intermodulation measurements made aboard BLUE RIDGE. Topside levels were found to be masked by serious sources of interference in PHASOR 90 uhf transmitting systems. The sources were determined to be in Prodelin coaxial cable connectors and the PHASOR 90 power divider. Section 5 continues reporting the effort in this area, giving results of laboratory tests wherein corrective measures were devised. The method of installing Prodelin coaxial connectors was drastically modified. UG-30D/U connectors and internal steel lock-washers were removed from the power divider and replaced with connectors not having nonlinear material.

Section 6 presents results of experiments conducted aboard IWO JIMA. This effort was directed toward locating and identifying the most important sources of topside-generated interference. New techniques were successfully applied to achieve this goal. It was, therefore, possible to devise a plan of minimum topside rfi control measures for LPH-class ships. The plan is minimal in the sense that removal of only the worst sources is recommended. It is not expected that implementation of the plan would reduce topside levels to those of FOX. It is expected, however, that a major improvement would result, at minimum cost.

1.2 SIGNIFICANCE OF FINDINGS

The measurements made aboard MOUNT WHITNEY, BLUE RIDGE, and IWO JIMA were the first opportunities to apply the concepts of very-high-order intermodulation interference[1] in a real shipboard environment. New insights were gained in this area which have resulted in increased ability to analyze IM interference frequency spectra. A separate report on this subject has been prepared.[2]

From another viewpoint, the results of work described in this document show that a new level of technical competence in the control of shipboard interference problems has been achieved. Results from the new amphibious command ships show that warships can be built in a way that yields low interference levels. In addition, the technical ability to select the worst topside interference sources on older ships offers hope that very worthwhile improvements may be economically feasible for active Fleet ships.

[1] Naval Electronics Laboratory Center Technical Note 1766, *Very High Order Intermodulation Products — Consideration of Spectrum Properties and Possible Applications for Shipboard Topside Interference*, by W. M. Chase and H. W. Guyader, 23 November 1970.

[2] Naval Electronics Laboratory Center Technical Report 1852, *Analysis of Very-High-Order Frequency Components of the Intermodulation Interference Spectrum*, by G. C. Salisbury, 26 October 1972.

SECTION 2

MOUNT WHITNEY TOPSIDE IM INTERFERENCE SURVEY

2.1 BACKGROUND

The tests aboard USS MOUNT WHITNEY were performed during the period 12-14 March 1971 while the ship was en route from Norfolk, Virginia, to Guantanamo, Cuba. During the test period, ambient conditions were close to ideal. The weather was clear and dry. With the ship steaming steadily through calm seas, there was a minimum of sea spray in the air. Thus, measured values were not temporarily lowered due to wetting of topside areas.

2.2 OBJECTIVES

The purpose of the tests was twofold: (a) provide data which permit overall quantitative assessment of topside-generated intermodulation (IM) interference levels, and (b) make a comparison to measured topside levels previously obtained aboard USS FOX. Time and circumstances did not permit extension of the work beyond these necessary tasks. Accordingly, other technically interesting tests, such as nonradiating tests of transmitter systems for residual IM interference generation or probing for specific topside interference contributors, were not performed. Measurements emphasized the 2-30MHz range; however, some data were obtained in the 30-50MHz range.

In addition to the IM interference tests, the topside was inspected for design details that were potential sources of interference generation. These observations are reported in section 2.5.

2.3 TEST INSTRUMENTATION/PROCEDURES

2.3.1 MOUNT WHITNEY TESTS

The task of evaluating the overall topside-interference-generating characteristics of MOUNT WHITNEY necessitated careful consideration of how the ship's systems were to be used. Referring to figure 2.1, it is seen that there is a total of seven broadband transmitting antennas in the 2-30MHz band. It was decided to radiate at least one frequency from each of these antennas at some time during the tests. Transmitting on antennas 3-1 and 3-3 was considered midship topside excitation. When these two antennas were used in combination with 3-2, aft excitation was obtained, and use of antennas 2-1, 2-2, and 2-3 supplied forward excitation. Antenna 2-4 was used in only one instance — in combination with 2-3 to observe the spectrum of an intermodulation product using complex modulation on one transmitter. The antennas were driven in the normal manner, using the ship's transmitters and highly selective transmitting multicouplers at the appropriate assigned test frequencies. Since most of the ship's transmitters are rated at 1kW, that power level with cw emission was used.

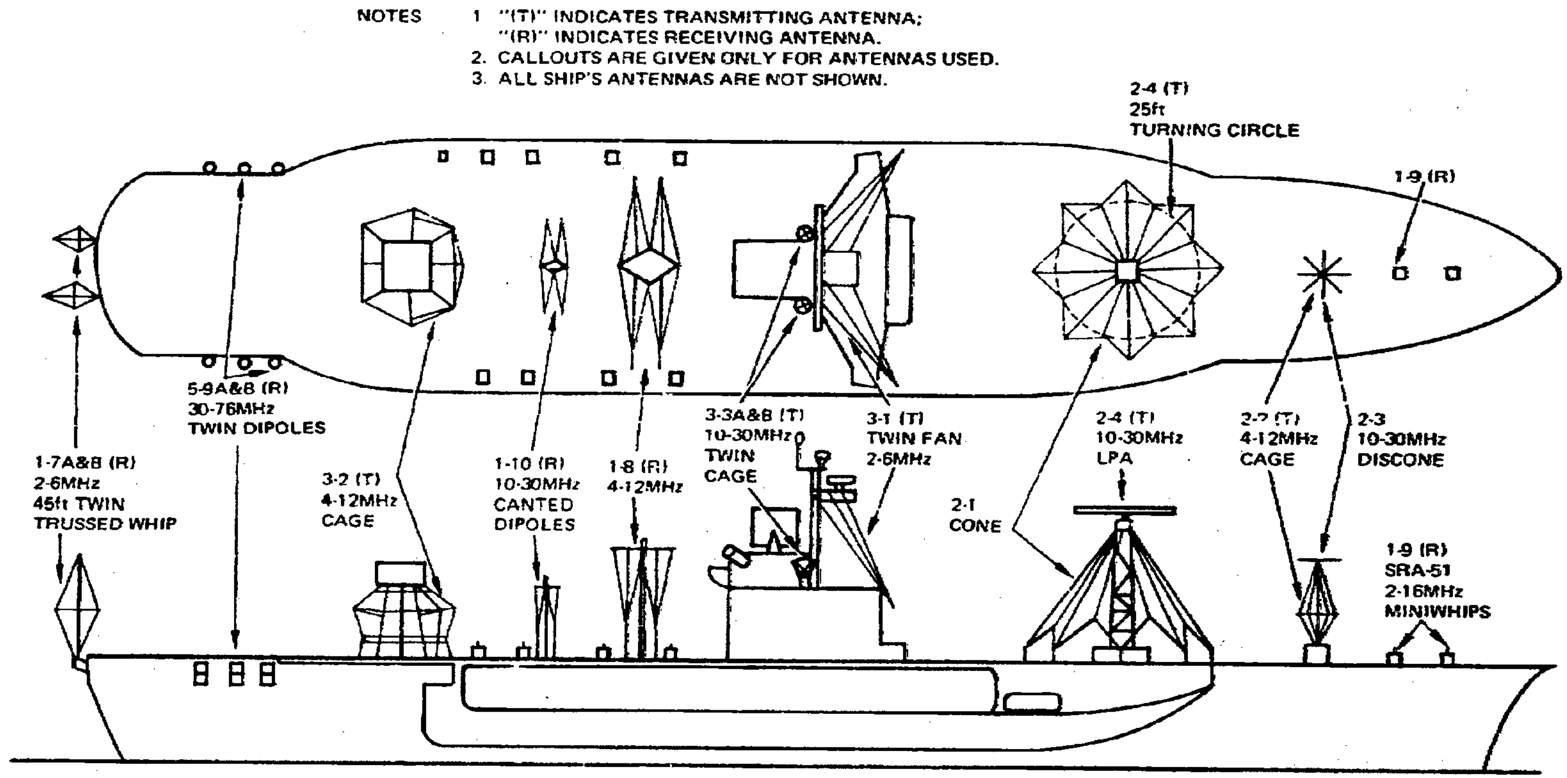


Figure 2.1. MOUNT WHITNEY antennas surveyed.

MOUNT WHITNEY has three broadband receiving antennas, each driving an appropriate SRA-38, -39, or -40 receiving multicoupler. In addition, there are 10 SRA-51 "miniwhips." All three broadband antennas and one of the forward SRA-51's were used during the tests to drive the receiving test equipment arranged as shown in figure 2.2.

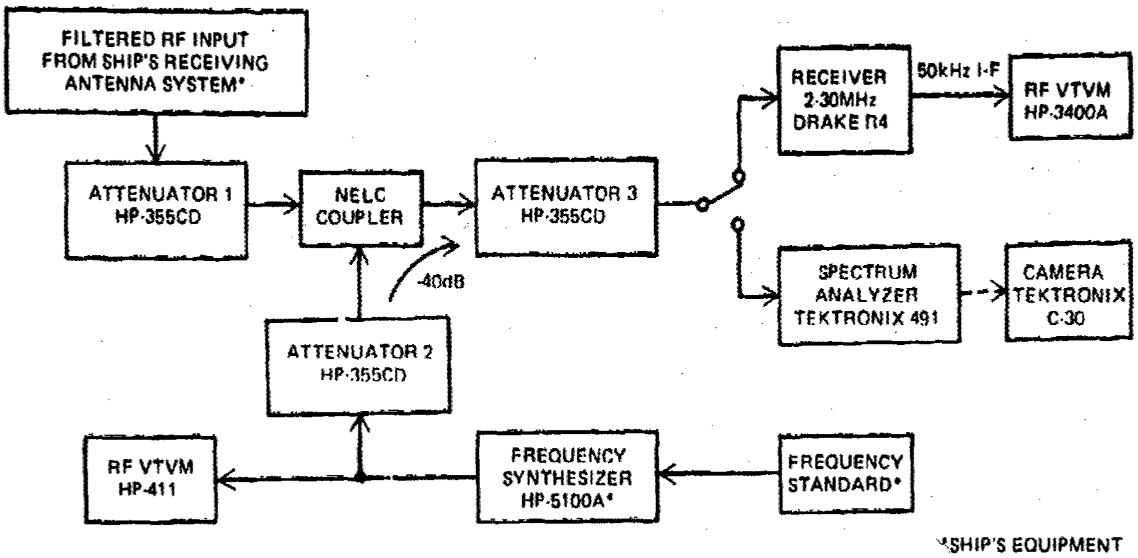


Figure 2.2. MOUNT WHITNEY hf IM interference measurement system.

Typical operation of this equipment started with attenuator 1 set for a large value of attenuation to preclude detection of external signals and attenuator 3 set to zero. The synthesizer was set on the desired frequency, and attenuator 2 was adjusted for detectable signal level at the R4 receiver. The receiver was then tuned, using a 400Hz i-f bandwidth. When a visual display was desired, the signal was applied to the spectrum analyzer, and 1kHz resolution was used. To observe an outside signal, attenuator 2 was set to maximum, while attenuator 1 was set to zero. Tuning of the ship's multicoupler or SRA-51 in the regular manner was accomplished. If too much signal was delivered to the receiver, attenuator 3 was adjusted for an output reading. The level was then matched, using the frequency synthesizer as before, with amplitude calibration provided by the HP-411 voltmeter.

In measuring the levels of intermodulation products at vhf frequencies, the test equipment was arranged as shown in figure 2.3. This illustrates the manner of accounting for losses by the test receiving systems in order to obtain interference levels referenced to the ship's vhf receiving system. The R4 receiver was not used in these tests because its upper frequency limit is 30MHz. Also, the upper limit of test receiving frequencies was established by the 50MHz maximum of the HP-5100A synthesizer.

The data obtained in these tests are summarized in figures 2.4 and tables 2.1 through 2.4, and are discussed in section 2.4.

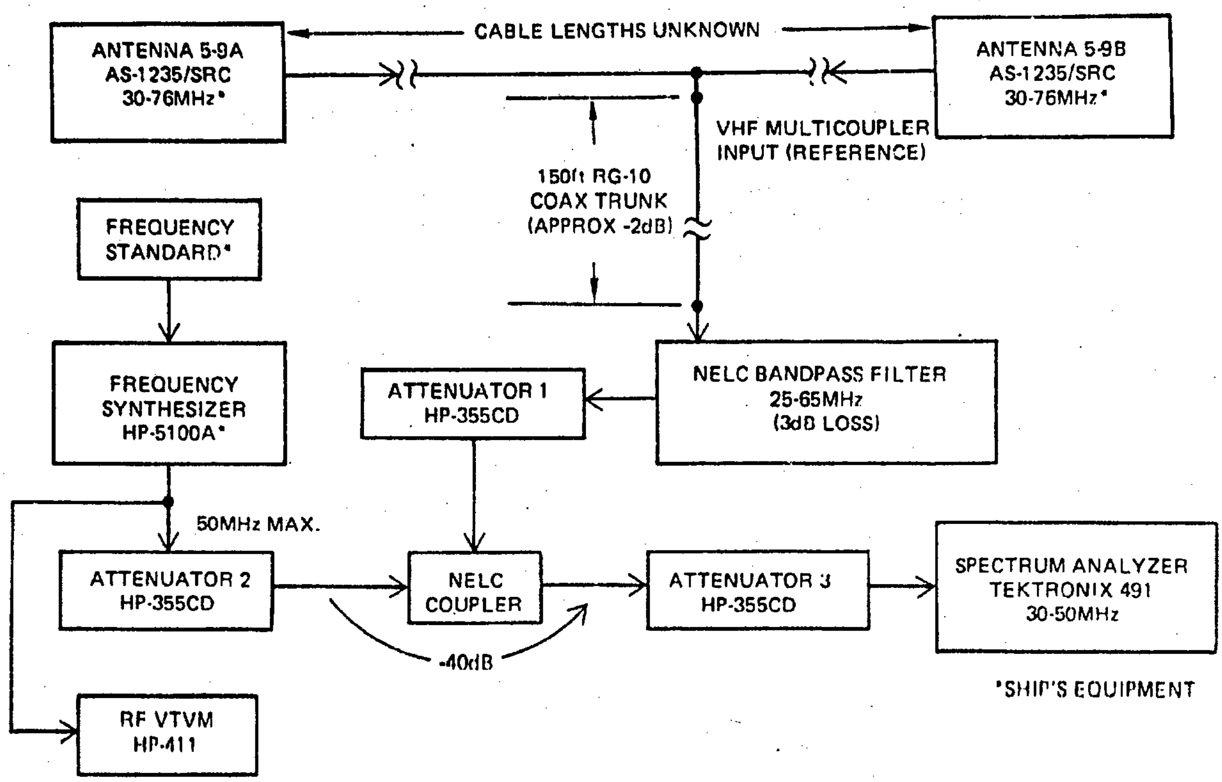


Figure 2.3. MOUNT WHITNEY vhf IM interference measurement system.

2.3.2 MOUNT WHITNEY/FOX COMPARATIVE TESTS

The physical differences between FOX and MOUNT WHITNEY are obvious, and are electromagnetically significant. Rigorous comparison of results demands consistent test conditions, which was not possible in this case. However, by exciting the ships with very nearly the same frequencies at the same power level and using centrally located transmitting antennas, a rough comparison was possible. The greatest deviation between assigned test frequencies was less than 1%, and, with the test transmitters adjusted for 250 watts, use of the midship antennas 3-1 and 3-3 most nearly satisfied these conditions. The receiving test equipment was again arranged as shown in figure 2.2, and the same procedures were followed. The measured MOUNT WHITNEY results are given in table 2.5, and are compared with the FOX data in table 2.6.

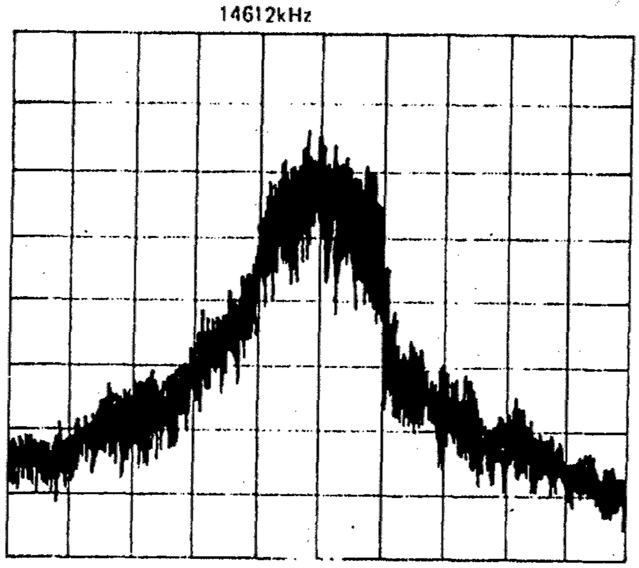
2.4 TEST RESULTS

The measured data given in tables 2.1, 2.2, and 2.3 are arranged to illustrate the effect of important parameters. Each table shows the measured interference levels arranged by order of intermodulation product and time sequence for a given transmitting antenna combination. Referring to table 2.1, it is seen that third-order products varied from a maximum of +33dB/μV to some value less than -10dB/μV. The time the measurement is made has a primary effect on the level obtained. The data also show that the order of the IM product being measured has an important effect on levels. The highest level at order 5 and above was 12dB/μV, and the lowest was less than -10dB/μV.

Comparison of the data in table 2.1 with those of tables 2.2 and 2.3 shows that changing to different transmitting antenna combinations did not have any pronounced effect on the interference levels. The forward transmitting antennas (table 2.3) seemed to yield somewhat lower levels. This impression probably arises from the fact that there were some instances where very low ambient noise levels masked the intermodulation levels.

The overall conclusion that can be drawn from these data is that the design and construction techniques applied to MOUNT WHITNEY have achieved a major reduction in topside intermodulation interference generation as compared to ships not so designed.

Figure 2.4 illustrates the effect of using complex modulation on one of the transmitters. The interference appears to have a flat noise-like quality over approximately a 4kHz band. Complex modulation of both transmitters would have resulted in greater bandwidth of significant intermodulation interference.



HORIZONTAL: 2kHz PER DIVISION
VERTICAL: 5dB RELATIVE POWER PER DIVISION
FREQUENCY RESOLUTION: 1kHz BANDWIDTH
RECEIVING ANTENNA: 1-10
INTERMODULATION PRODUCT: 2F4-F2

TRANSMITTING SYSTEM

TRANSMITTER 1	12,433.5kHz (F2), 1kW AVERAGE, CW, ANTENNA 2-3
TRANSMITTER 2	10,255kHz (F4), 1kW PEP, 125W AVERAGE, 8 TONE MULTIPLEX MODULATION, ANTENNA 2-4

Figure 2.4. MOUNT WHITNEY received topside IM spectrum complex modulation on one transmitter.

TABLE 2.1. MOUNT WHITNEY RECEIVED HF TOPSIDE IM LEVELS – 1kW POWER APPLIED TO MIDSHIP ANTENNAS (12-13 MARCH 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2276 (F1)	750	3-1
2	12433.5 (F2)	1000	3-3
3	22130 (F3)	1000	3-3

RECEIVED LEVELS

IM Function	IM Frequency, kHz	Local Time	Ambient,* dB/μV	IM Level,** dB/μV	Receiving Antenna No.
F3-2F1	17581	2055 (12 Mar)	--	26	1-10
F3-2F1	17581	2059 (12 Mar)	--	24	1-10
F3+2F1	26679	2110 (12 Mar)	--	33	1-10
2F2-F3	2737	0900 (13 Mar)	--	17	1-7
3F1	6825	0917 (13 Mar)	--	27	1-8
2F2-F1	22592	1050 (13 Mar)	-10	***	1-10
2F1+F3	26680	1057 (13 Mar)	-10	***	1-10
5F1	11375	0958 (13 Mar)	0	7	1-8
5F1	11375	1000 (13 Mar)	-6	12	1-10
3F1-F2+F3	16251.5	1016 (13 Mar)	-10	***	1-10
7F1	15925	1010 (13 Mar)	-8	2	1-10
9F1	20475	1045 (13 Mar)	-21	-8	1-10

*Level existing when test transmitters are off the air using 400Hz bandwidth. When not given, ambient is very small compared to IM level.

**IM level reference is to receiver input with transmitters operating at indicated power. No correction is made for receiving multicoupler loss.

***IM not detectable in presence of ambient level.

TABLE 2.2. MOUNT WHITNEY RECEIVED HF TOPSIDE IM LEVELS – 1kW POWER APPLIED TO AFTER ANTENNAS (13 MARCH 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2276 (F1)	750	3-1
2	12433.5 (F2)	1000	3-3
3	10255 (F4)	1000	3-2

RECEIVED LEVELS

IM Function	IM Frequency, kHz	Local Time	Ambient,* dB/μV	IM Level,** dB/μV	Receiving Antenna No.
2F4-F2	8076.5	1403	-6	39	1-8
2F4-F1	18234	1422	-	22	1-10
3F2-2F4	16790.5	1418	-17	6	1-10
2F4-3F1	13682	1406	-23	-5	1-10
4F4-3F2	3719.5	1345	-19	-9	1-7
3F4-4F1	21661	1428	13	***	1-10
2F4-7F1	4578	1353	-19	***	1-7
10F4-7F2	15515.5	1414	-1	***	1-10

*Level existing when test transmitters are off the air using 400Hz bandwidth. When not given, ambient is very small compared to IM level.

**IM level reference is to receiver input with transmitters operating at indicated power. No correction is made for receiving multicoupler loss.

***IM not detectable in presence of ambient level.

TABLE 2.3. MOUNT WHITNEY RECEIVED HF TOPSIDE IM LEVELS – 1kW POWER APPLIED TO FORWARD ANTENNAS (13 MARCH 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2276 (F1)	1000	2-1
2	12433.5 (F2)	1000	2-3
3	10255 (F4)	1000	2-2

RECEIVED LEVELS

IM Function	IM Frequency, kHz	Local Time	Ambient,* dB/μV	IM Level,** dB/μV	Receiving Antenna No.
2F4-F2	8076.5	1618	19	***	1-8
2F4-F1	18234	1643	-3	7	1-10
2F4-F2	8076.5	1734	1	21	1-9
2F4-3F1	13682	1625	16	***	1-10
3F2-2F4	16790.5	1638	-16	4	1-10
2F4-3F1	13682	1740	11	***	1-9
4F4-3F2	3719.5	1609	-27	***	1-7
3F4-4F1	21661	1646	-14	***	1-10
4F4-3F2	3719.5	1708	-7	***	1-9
2F4-7F1	4578	1611	-27	***	1-7
2F4-7F1	4578	1718	-5	***	1-9
10F4-7F2	15515.5	1631	3	***	1-10

*Level existing when test transmitters are off the air using 400Hz bandwidth. When not given, ambient is very small compared to IM level.
**IM level reference is to receiver input with transmitters operating at indicated power. No correction is made for receiving multicoupler loss.
***IM not detectable in presence of ambient level.

Table 2.4 summarizes the results of the measurements of intermodulation levels when receiving at vhf frequencies. The levels at the vhf receiver system input appear somewhat higher than the preceding hf results. Since the levels at the vhf receiver input will be reduced by the vhf multicoupler (approximately 2dB for SRA-60), they are slightly higher even when compared at equivalent points in the systems. This does not mean that severe interference will always occur to vhf communications by reason of this mechanism. Frequency modulation is commonly used at very high frequencies; thus, the vhf system may not be affected. On the other hand, hf systems frequently use FSK modulation (as in fig. 2.4), which is a low-modulation-index form of FM. Thus, intermodulation products could be expected to have some FM characteristics in certain cases. These observations suggest that a careful analysis, based on a larger data base, is needed.

TABLE 2.4. MOUNT WHITNEY RECEIVED VHF TOPSIDE IM LEVELS -- 1kW POWER APPLIED TO AFTER ANTENNAS (14 MARCH 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	10255 (F4)	1000	3-2
2	14517 (F5)	1000	3-3
3	Not used		

RECEIVED LEVELS

IM Function	IM Frequency, kHz	System Loss, dB	IM Level,* dB/μV	VHF System Input Level,** dB/μV
3F4	30765	5	21	26
F5+2F4	35027	5	18	23
2F5+F4	39289	5	[illegible]	
3F5	43551	5	11	19
4F5-F4	47813	5	0	5
6F4-F5	47013	5	13	18
7F4-2F5	42751	5	-3	2
5F5-4F4	31565	5	4	9

*Ambient noise less than receiver system noise. IM not detectable at levels below -5dB/μV, approximately.
**All levels measured using antenna 5-9.

Table 2.5 summarizes the data taken with 250W transmitter power. These data were taken under similar conditions to those given in table 2.1, so a comparison should show the effect of transmitter power. Comparing the data, it is seen that there is little apparent difference. In some cases, intermodulation level increases with transmitter power; in other cases, the converse is true. Indications are that the differentials arise more from the time variability of shipboard levels than from change in transmitter power. This is consistent with earlier results obtained at NELC, which showed very small changes as transmitter power changed from 50W to 500W. Extrapolation to higher power levels (MOUNT WHITNEY has several 5kW transmitters) would be unwise. This is because the physics of the interference-causing mechanisms may change at the higher excitation power levels.

TABLE 2.5. MOUNT WHITNEY RECEIVED HF TOPSIDE IM LEVELS 250W POWER APPLIED TO MIDSHIP ANTENNAS (12 MARCH 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2276 (F1)	250	3-1
2	12433.5 (F2)	250	3-3
3	22130 (F3)	250	3-3

RECEIVED LEVELS

IM Function	IM Frequency, kHz	Local Time	Ambient,* dB/μV	IM Level,** dB/μV	Receiving Antenna No
2F2-F3	2737	1103		31	1-7
3F1	6828	[illegible]		[illegible]	1-8
[illegible]	[illegible]	[illegible]		18	1-8
5F1	11,380	1402	-13	4	1-8
5F1	11,380	1408	-19	-2	1-10
5F1	11,380	1935	4	***	1-10
7F1	15932	1438	-7	8	1-10
9F1	20484	1510	-10	***	1-10

*Level existing when test transmitters are off the air using 400Hz bandwidth. When not given, ambient is very small compared to IM level.
**IM level reference is to receiver input with transmitters operating at indicated power. No correction is made for receiving multicoupler loss.
***IM not detectable in presence of ambient level.

Table 2.6 shows the comparison to levels measured aboard FOX. It was necessary to adjust the raw data of both tests to arrive at equivalent comparison points in the two ships' systems. The values given represent the available interference power in the two ships' respective receiving antennas. As the data show, third-order levels are about the same, but fifth and seventh orders are significantly lower on MOUNT WHITNEY, while ninth order is very low on both ships.

TABLE 2.6. COMPARISON OF TOPSIDE-GENERATED HARMONIC LEVELS ON MOUNT WHITNEY (12 MARCH 1971) AND FOX (JUNE 1970).

TRANSMITTING SYSTEMS

MOUNT WHITNEY				FOX			
Transmitter No.	Frequency, kHz	Power, W	Antenna No.	Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2276	250	3-1	1	2272	250	2-1
2	12433.5	250	3-3	2	12335	250	2-9
3	22130	250	3-3	3	22136	250	2-9

RECEIVED LEVELS

MOUNT WHITNEY			FOX				
IM Function	IM Frequency, kHz	IM Level,* dB/μV	IM Function	IM Frequency, kHz	IM Level,* dB/μV Max	Avg	Min
3F1	6828	33	3F1	6816	44	39	31
5F1	11380	7	5F1	11360	32	22	24
7F1	15932	1	7F1	15904	31	21	21
9F1	20484	-10**	9F1	20448	<8	<6	<2

*Levels given are corrected for receiving multicoupler loss on MOUNT WHITNEY and antenna mismatch loss on FOX.

**Level is atmospheric noise level. 9F1 is not detectable under these conditions. This condition also existed on FOX; however, ambient noise levels were higher in the latter case.

2.5 TOPSIDE INSPECTION OBSERVATIONS

While touring the topside antenna area on 11 March, members of the NELC team observed many topside design details the characteristics of which conform to ideas long advocated by investigators of topside-generated interference. However, during the period of MOUNT WHITNEY's construction, advances in the art of controlling this type of interference had been made which could not have been included in the ship construction contract. One practice which is now considered obsolete and which was followed on MOUNT WHITNEY is the use of rfi bondstraps bolted in place or otherwise removable. This sort of fitting is easily lost, and imposes a continual maintenance problem on the ship. Present engineering practice would avoid this problem by replacing the metallic object, which needs bonding, with a nonmetallic one designed to serve the same function. This eliminates the nonlinear junctions and the need for bondstraps. One example of a possible application of these methods onboard MOUNT WHITNEY would be replacement of the jackstaff.

2.6 CONCLUSIONS AND RECOMMENDATIONS

a. There is no doubt MOUNT WHITNEY enjoys a substantially lower level of received topside-generated self-interference. After adding receiving multicoupler losses to the levels measured in these tests, resultant levels are equivalent, or slightly below, those obtained on BUNKER HILL, the NELC test facility. Results obtained at orders 5, 7, 9, and higher are especially encouraging because, for a given number of transmitters radiating, the higher orders result in many more interference signals than the third order does. Roughly, MOUNT WHITNEY levels appear to be 30-35dB lower than warships which have neither been designed for low topside interference nor have had "fixes" applied.

b. The comparison of MOUNT WHITNEY to FOX shows a clear advantage for the former ship. The advantage is most clear for fifth- and higher-order products.

c. At the present time, a major effort directed toward topside rfi "cleanup" is not warranted aboard MOUNT WHITNEY. Maintenance of present low levels is expected to be a future problem. Deterioration of some rfi bondstraps topside was noticeable at the time of these tests. Piecemeal removal of potential interference contributors – bonded items vulnerable to loss of bonding – and their replacement with appropriate standard glass-reinforced plastic (GRP) items now available or in development stages is recommended to reduce life-cycle maintenance costs.

d. Interference to vhf receiving systems by reason of topside intermodulation between hf transmissions is a possibility. (See section 3 for a more thorough testing of this possibility.)

SECTION 3

BLUE RIDGE HF/VHF TOPSIDE IM INTERFERENCE SURVEY

3.1 BACKGROUND

The hf and vhf measurement results given in this section were obtained aboard USS BLUE RIDGE during the period 2-5 August 1971. The entire task assignment included measurements at hf, vhf, and uhf and comparison of results to those obtained aboard MOUNT WHITNEY in March 1971. The uhf results are given in section 4. Since uhf data were not obtained aboard MOUNT WHITNEY, the comparison of results (given in this section) is limited to hf and vhf.

3.2 TEST INSTRUMENTATION/PROCEDURES

The antennas used during the hf/vhf tests are shown in figure 3.1. Antenna 2-3 was not used due to poor impedance match. This necessitated substitution of the LPA (antenna 2-4).

In making specific intermodulation product measurements, the test equipment was arranged in the receiver room as shown in figure 3.2.

Figure 3.2A shows the interface between the test equipment and the ship's receiving system. The functions of the three transmitter monitor and control units were to allow test personnel direct control of test transmitter keying, while observing the presence of the radiated transmitter fundamental frequency energy. The control units also permitted the direct comparison of the transmitter carrier frequencies to the frequency standard by the "zero beat" method. In test operations, it is necessary to show that intermodulation energy levels generated in the monitor-control are not sufficient to affect measurement results. This was done by sequentially disconnecting the rf input to the monitors, while observing the level of a received IM product. Since there was no measurable effect, the monitor-control equipments did not influence results. This check was done whenever a new transmitting frequency was used or the transmitting antennas were changed.

Figure 3.2B shows the arrangement of the receiving test equipment. The two separate receivers are the reference IM receiver and the data IM receiver. The reference IM receiver was set to the third harmonic (7386kHz) of the lowest transmitting frequency (2462kHz). This was done to obtain a reference signal for evaluating variability of topside conditions. The data IM receiver has the advantage of being quickly and accurately changed in frequency. The noise figure is approximately 14dB, which yields a system noise level of $-27dB/\mu V$ with 400Hz bandwidth. Use of the synthesizers in the test system greatly accelerated test operations by eliminating the need to change crystals in the Drake receiver.

To observe IM spectra with heavy transmission traffic demands, nine of the ship's transmitters were operated as shown in table 3.1. Since none of the transmitters were operated above 10MHz, a sweep of the spectrum from 10-30MHz could be made using the equipment arrangement of figure 3.3. The spectrum analyzer was arranged to show either 10-20MHz or 20-30MHz

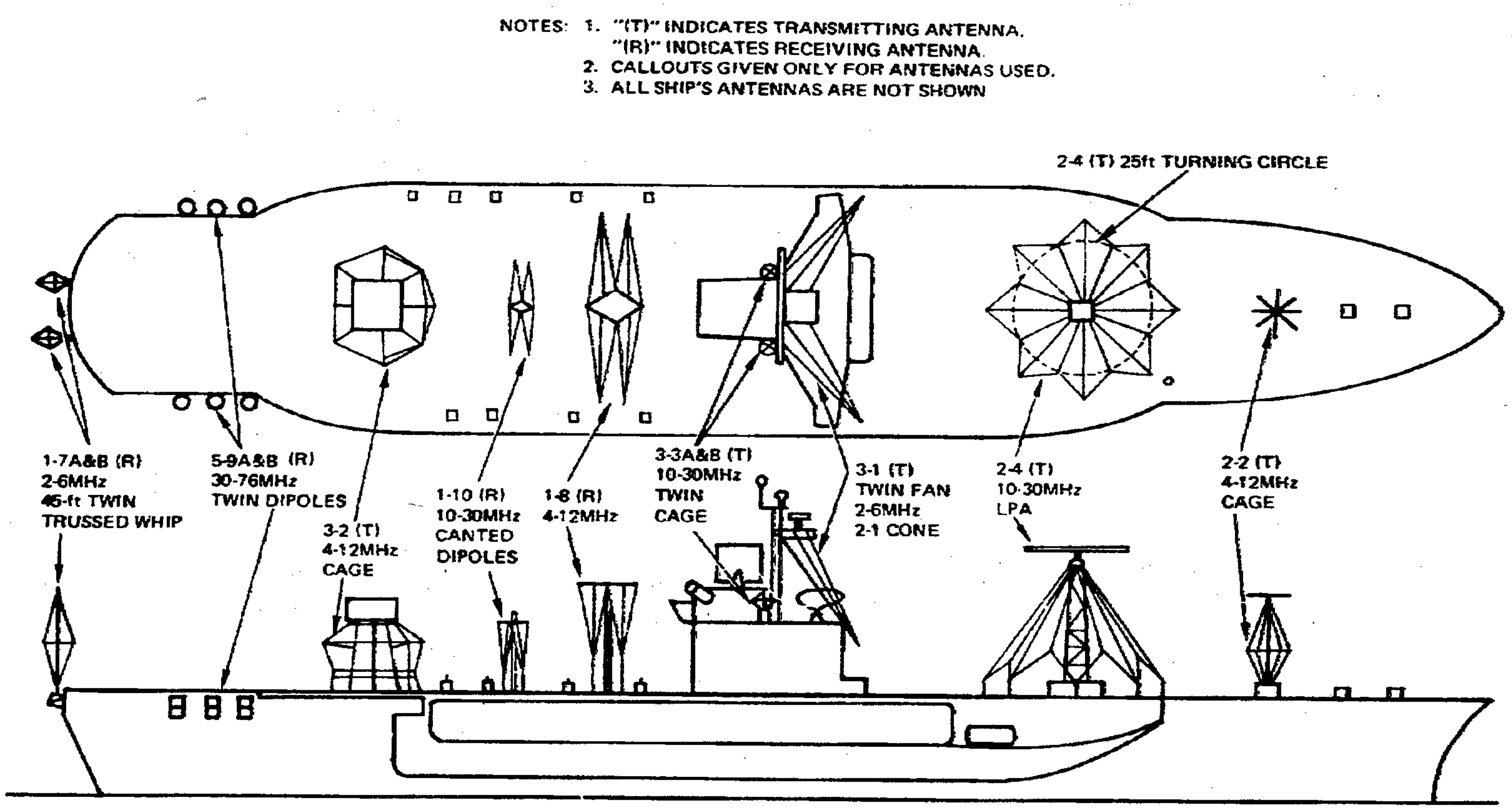


Figure 3.1. BLUE RIDGE hf/vhf antennas surveyed.

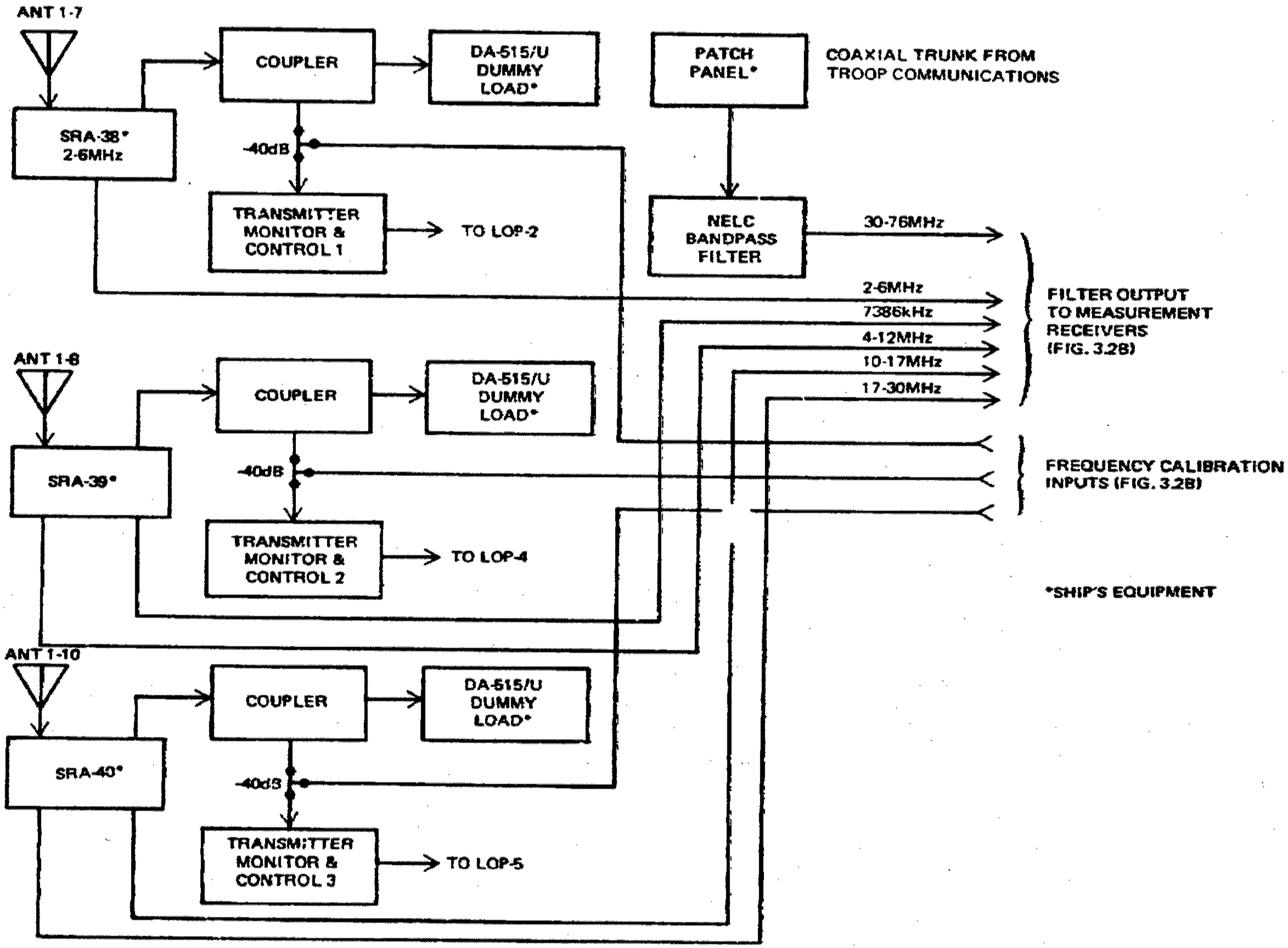


Figure 3.2A. BLUE RIDGE hf/vhf receiving test equipment/ship's receiving system interface.

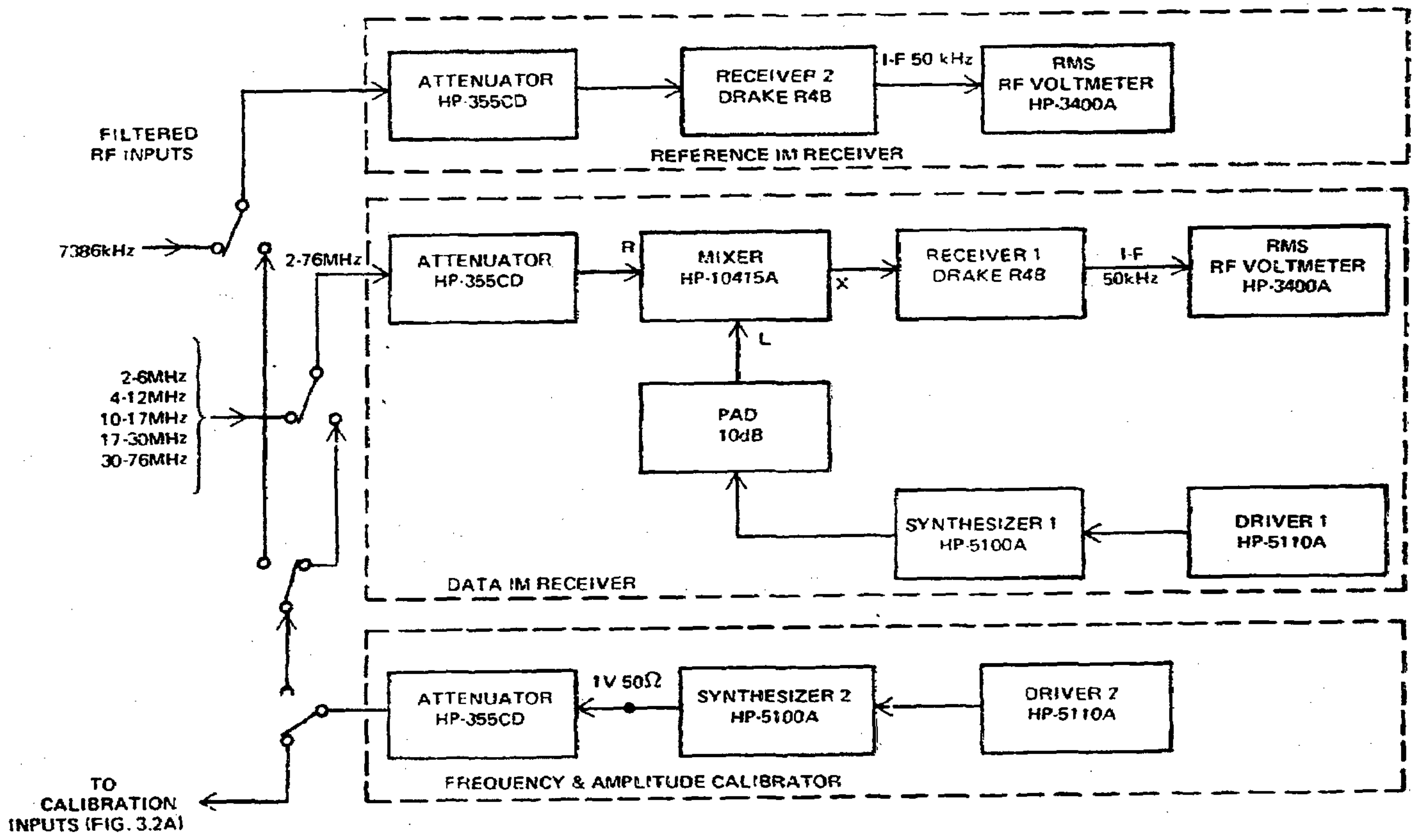


Figure 3.2B. BLUE RIDGE hf/vhf receiving test equipment.

spectra as desired. The exposure time of the camera was set equal to the time required for one spectrum analyzer sweep. To obtain the data, the appropriate filter of the SRA-40 multicoupler was tuned in 250kHz increments, with one exposure of the camera film per filter tuning increment. The function of the oscilloscope was to provide an auxiliary spectrum display to permit viewing by the operator with the camera in place over the spectrum analyzer display.

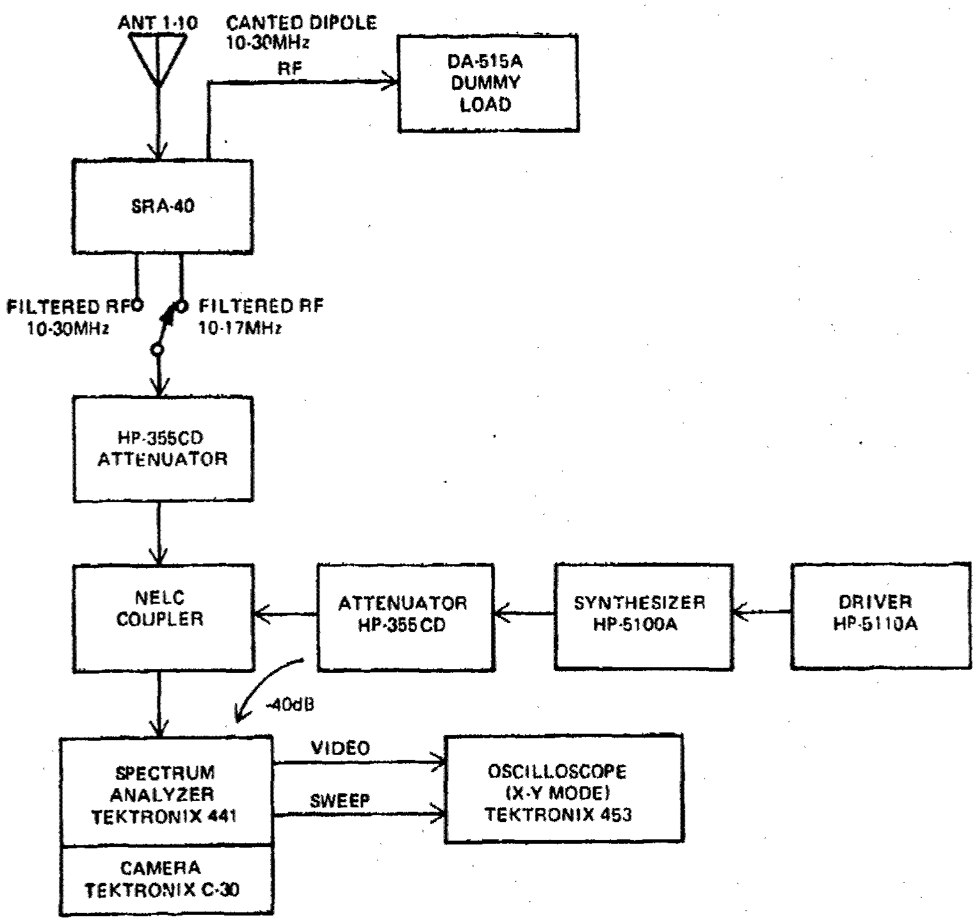


Figure 3.3. Receiving equipment for BLUE RIDGE maximum radiation test.

TABLE 3.1. TRANSMITTING EQUIPMENT USED IN BLUE RIDGE MAXIMUM RADIATION TEST.

Transmitter No. (SRC-23)	Frequency, kHz	Emission	Avg Power, W	Antenna	Coupler No.
3-2	2240	3A7J	700	Twin fan	16
9-1	3200	3A7J	700	Cone	35-6, frame 39
2-2	3357	3A7J	800	Twin fan	16, frame 65-72 P&S
7-1	4328	1.24F1	700	Cone	35-6
3-1	6218.5	3A3J	700	Cage	36-6, frame 18
8-1	8518	1.24F1	700	Cage	36-8, frame 18
1-1	9250	1.24F1	700	Cage	36-4, frame 18
4-2	2075	3A7J	600	Twin fan	16
11-1	3262	3A7J	500	Cone	35-1

3.3 TEST RESULTS

Results of the measurements are given in figures 3.4 and 3.5 and in tables 3.2 through 3.5. Figure 3.4 shows the level of the reference third harmonic as a function of time. Tables 3.2 through 3.5 summarize results of all the other specific intermodulation product measurements exclusive of the third harmonic. Figure 3.5 is a spectrum sweep obtained during the maximum radiation test. In addition, results of uhf ambient noise measurements made during the maximum radiation period are presented in table 3.6, and the receiving equipment used is shown in figure 3.6.

These results are discussed in detail below.

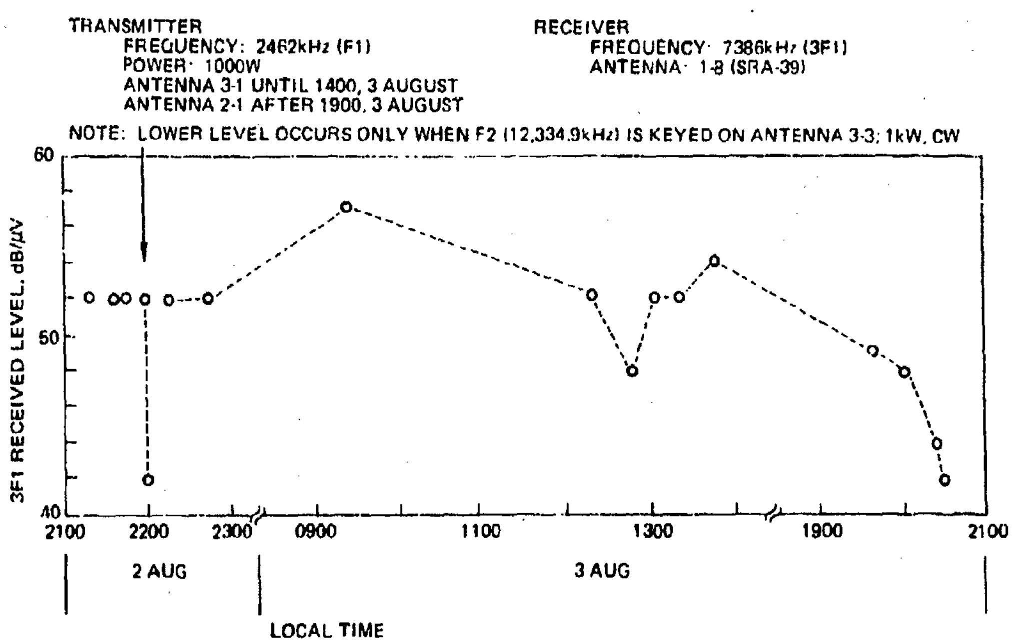


Figure 3.4. Third harmonic level as a function of time BLUE RIDGE hf/vhf IM interference measurements.

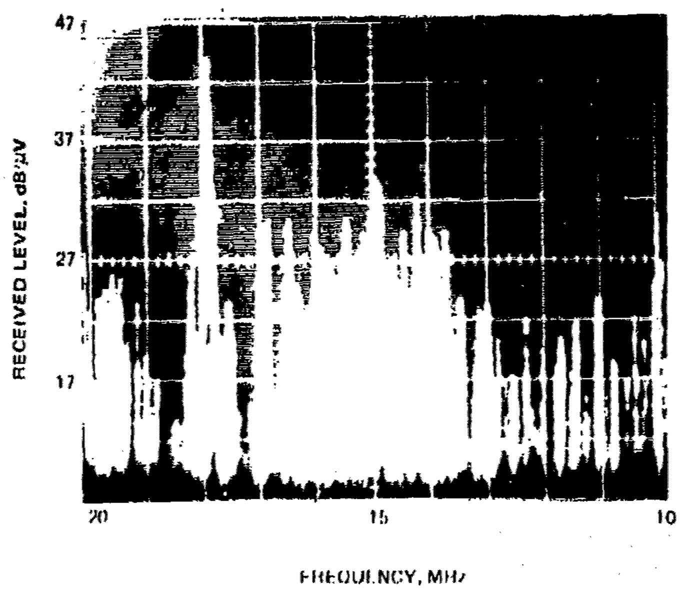


Figure 3.5. BLUE RIDGE maximum radiation test frequency spectrum.

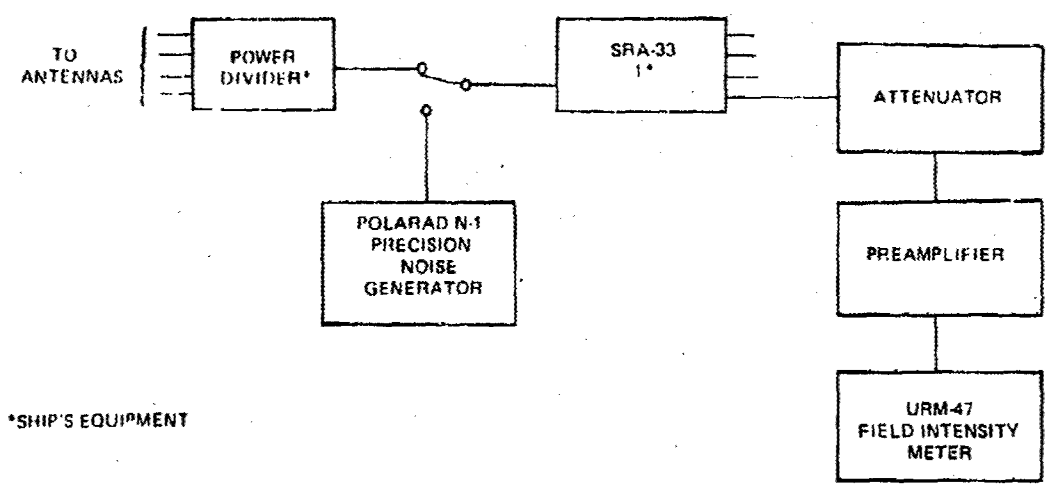


Figure 3.6. Receiving equipment used to measure uhf ambient noise levels during BLUE RIDGE maximum radiation test.

TABLE 3.2. BLUE RIDGE RECEIVED HF TOPSIDE IM LEVELS 1kW POWER APPLIED TO MIDSHIP ANTENNAS (2 AUGUST 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2462 (F1)	1000	3-1
2	12334.9 (F2)	1000	3-3
3	22130 (F3)	1000	3-3

RECEIVED LEVELS

IM Function	IM Frequency, kHz	IM Level, dB/μV	Receiving Antenna No.
F3+2F1	27054	30	1-10
F3-2F1	17581	30	1-10
2F2-F3	2539.8	23	1-7
2F2-F1	22207.8	32	1-10
5F1	12310	32	1-10
3F1-2F2+F3	4846.2	*	1-10
7F1	17234	10	1-10

*IM not detectable in presence of ambient level. Operating transmitters at indicated power produced no increase in received energy.

TABLE 3.3. BLUE RIDGE RECEIVED HF TOPSIDE IM LEVELS 1kW POWER APPLIED TO FORWARD ANTENNAS (3 AUGUST 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2462 (F1)	1000	2-1
2	12334.9 (F2)	1000	2-2
3	11264.5 (F4)	1000	2-4

TABLE 3.3 (CONTINUED)

RECEIVED LEVELS

IM Function	IM Frequency, kHz	IM Level, dB/μV	Receiving Antenna No.
F1+F2+F4	26061.4	14	1-10
2F4-F2	10194.1	37	1-10
2F4-F1	20067	23	1-10
2F4-3F1	15143	7*	1-10
3F2-2F4	14475.5	QRM**	1-10
4F4-3F2	8053.3	4 (QRM)**	1-8
3F4-4F1	23945.5	-7	1-10
2F4-7F1	5295	6 (QRM)**	1-7
10F4-7F2	26303.5	-19***	1-10

*Distorted music audible on IM.

**Levels are received off-ship signals (QRM) which mask IM level.

***Level is ambient only. Operating transmitters at indicated power level produced no increase in received energy.

TABLE 3.4. BLUE RIDGE RECEIVED HF TOPSIDE IM LEVELS 1kW POWER APPLIED TO AFTER ANTENNAS (3 AUGUST 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
1	2462 (F1)	1000	3-1
2	12334.9 (F2)	1000	3-3
3	11264.5 (F4)	1000	3-2

RECEIVED LEVELS

IM Function	IM Frequency, kHz	IM Level, dB/μV	Receiving Antenna No.
2F4-F2	10194.1	36	1-10
2F4-F1	20067	33	1-10
3F2-2F4	14475.5	15	1-10
2F4-3F1	15143	12	1-10
4F4-3F2	8053.3	-1	1-8
3F4-4F1	23945.5	11	1-10
2F4-7F1	5259	-17	1-7
10F4-7F2	26303.5	-22*	1-10

*Level is ambient only. Operating transmitters at indicated power level produced no increase in received energy.

TABLE 3.5. BLUE RIDGE RECEIVED VHF TOPSIDE IM LEVELS – 1kW POWER APPLIED TO AFTER ANTENNAS (3 AUGUST 1971).

TRANSMITTING SYSTEM

Transmitter No.	Frequency, kHz	Power, W	Antenna No.
2	15052.5 (F5)	1000	3-3
3	11264.5 (F4)	1000	3-2

RECEIVED LEVELS

IM Function	IM Frequency, kHz	IM Level, dB/μV	Receiving Antenna No.
3F4	33793.5	40	5-9
2F5+F4	41369.5	3	5-9
F5+2F4	37581.5	25	5-9
3F5	45157.5	22	5-9
4F5-F4	48945.5	6	5-9
7F4-2F5	48746.5	-16*	5-9
5F5-4F4	30204.5	6	5-9

*IM audible in speaker. Operating transmitters at indicated power produced no measurable increase of received energy, however. Therefore, IM is much weaker than level given.

TABLE 3.6. RELATIVE UHF NOISE LEVELS RECEIVED DURING BLUE RIDGE MAXIMUM RADIATION TEST.

Frequency, MHz	Noise Figure, dB	Test A Level, dB	Test B Level, dB			Test C Level, dB
			1045 hr	1050 hr	1055 hr	
245	8	6	6	6	8	6
255	7.5	6	7.5	8	8.5	6
265	11.5	9	10.0	10.7	11	8
275	9.0	7.5	8.5	9	9	6
285	5.5	4	6.5	7	7	4

Test A: Normal ship hf transmitter usage, 0940 hr
Test B: Nine transmitters radiated
Test C: Return to Test A conditions at 1535 hr
Overall average rise, Test B = 1.6 dB

3.3.1 SPECIFIC IM MEASUREMENTS

The difference in the overall average level of the reference third harmonic (52dB/μV) and the overall average of all other third-order products (29dB/μV) is large enough to be significant. It can be hypothesized that the measurement results arise from two systems of causes.

The stronger causes were in the transmitting system of the lowest frequency (F1). These more important nonlinearities were driven very well by F1 but, because of antenna decoupling, to a lesser degree by test transmitters at other frequencies.

There are indications that some of the most important nonlinearities contributing to the high third harmonic level were also excited by other transmitter frequencies. Referring to figure 3.4, it is seen that the level of 3F1 dropped 10dB when F2 was keyed. This "loading" effect has been observed frequently in other shipboard tests. Usually, it is considered that the energy from the second transmitter causes a "bias" to be developed in one or more strong nonlinearities, which in turn causes an increase in "conversion loss," thereby producing a lowered 3F1 received level. Since F2 is roughly 12MHz, it might appear that excitation of the nonlinearities by this frequency would mean the idea of the interference source being within the 2-6MHz transmitting system is incorrect. However, antennas of the twin-fan type, similar to 3-1, often function well at 12MHz. Also, antenna 3-3, which radiated the 12MHz energy, is physically very close to antenna 3-1, and shares the same supporting superstructure (as shown in fig. 3.1). Thus, the possibility of close coupling between these two antennas exists, at least near 12MHz. Also, the "loading" effect existed only for this particular combination of antennas and frequencies.

It is therefore a reasonable hypothesis that two groups of nonlinearities were operating during the specific IM measurements. One group had its strongest contributor(s) in the broadband circuitry of antenna 3-1 — that is, all components beginning with the transmitting multicoupler combiner and extending outboard in the direction of power flow to the last piece which is part of identifiable antenna hardware. The second group consisted of all the topside interference-generating nonlinearities which appear to be more or less equally excited by all transmitting combinations.

The significance of the hypothesis is that, when two or more transmitter signals are radiated using antenna 3-1, very much higher levels of intermodulation interference can be expected in the ship's receiving system than when other transmitting combinations are used. The levels expected would be much like those aboard untreated warships measured earlier in the rfi program. IM products through at least the ninth order will be of significance when 1kW transmitters are used. When higher transmitter powers are used, higher orders than the ninth are likely to become significant. On the other hand, using transmitters on other antennas will result in greatly reduced IM levels. Not using antenna 3-1 is an unsatisfactory restriction upon operational usage of the ship's communications system. It will be necessary to locate and correct the problem(s).

3.3.2 MAXIMUM RADIATION TEST

The data given in figure 3.5 are not very informative about interference conditions. The primary reason is that there is no way to differentiate between interference and desired signals. For example, there is a spectrum shown in figure 3.5 at a level of about 27dB/μV just above 15MHz, which is about 200kHz wide. Even so, the ship was maintaining high-quality reception on an important channel in this frequency range all during the maximum radiation test. Therefore, at least some of the energy was desired signal, not interference.

It was, of course, planned to take additional spectrum data with minimum radiation. However, the first part of the experiment took too long. Sufficient diurnal change in propagation conditions occurred so that remote signals, etc., caused large segments of the spectrum to contain more energy than when all transmitters were radiating. Also, data recording during this latter phase was hampered by failure of the camera shutter, and visual observation of the spectrum display was necessary.

These results are of only instructive value. Should another such measurement be attempted, more useful results would be obtained by using a more sensitive spectrum analyzer (with a more reliable camera) and a more rapid keying sequence of the transmitters. Even with the manually operated filters of the SRA-40, it should be possible to perform at least two sweeps in a 1-hour period. If the proper starting time were chosen, propagation conditions could be expected to remain sufficiently stable to obtain good data in that length of time.

The uhf noise increase during this test shown in table 3.6, is interesting. Compared to the other forms of interference reported in NELC Letter Report 2100-238,[3] these results are not regarded as a serious threat to present communications systems. However, some future systems may need to make allowance for this effect. UHF SATCOM systems, for example, may be outside-ambient-noise-limited as opposed to internal-receiver noise limited. This additional noise produced the same audible sound in the earphones as the output of the calibrated noise generator when it was used to obtain the same meter deflection. Therefore, it can be considered white noise, to a first approximation.

3.4 BLUE RIDGE/MOUNT WHITNEY COMPARISON

The summary comparison of results obtained aboard MOUNT WHITNEY with those obtained aboard BLUE RIDGE is given in table 3.7. It should be noted that the results given for BLUE RIDGE do not include the data of figure 3.4. These are omitted on the basis of the plausible hypothesis discussed above that is, the third harmonic levels were due primarily to the transmitting system.

Technically speaking, the overall differential factor is 13dB in favor of MOUNT WHITNEY at hf. This much difference in overall averages is usually considered sufficient to be statistically significant. However, the most striking results are the very low levels obtained aboard MOUNT WHITNEY from time to time. Actually, the MOUNT WHITNEY results are so low that it is probably not very important that BLUE RIDGE had 13dB higher topside-generated levels. For a number of years, topside-rfi-reduction research work at NELC has had a technical goal well matched by the performance of BLUE RIDGE as given in table 3.7. Since the seventh and higher orders of intermodulation interference average approximately 1μV or less, they can be reasonably termed unimportant interference. This premise seems to correlate with the lack of difficulty in receiving remote stations during the maximum radiation test described earlier.

However, BLUE RIDGE does have considerably higher transmitting-system-generated intermodulation interference than MOUNT WHITNEY.

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[3]Naval Electronics Laboratory Center Letter Serial 2100-238, Subject: UHF Intermodulation Interference USS BLUE RIDGE (LCC 19), 27 August 1971.

Aboard the latter ship, there were no peculiarities of the measurement results as were obtained aboard BLUE RIDGE.

At vhf, there was no measurable difference in intermodulation levels aboard the two ships. Third-order IM products, for example, differed by only 1.5dB: MOUNT WHITNEY having an average level of 21dB/μV while BLUE RIDGE had 22.5dB/μV. This differential approximates the experimental accuracy to be expected in shipboard measurements.

TABLE 3.7. COMPARISON OF RECEIVED HF TOPSIDE IM LEVELS ON MOUNT WHITNEY AND BLUE RIDGE.

IM Order	MOUNT WHITNEY IM Levels, dB/μV			BLUE RIDGE IM Levels, dB/μV			Relative IM Levels (BLUE RIDGE - MOUNT WHITNEY) dB/μV (avg)
	Min	Avg	Max	Min	Avg	Max	
3	-10*	18	39	14	29	37	+11
5	-10*	2	12	12	15	32	+13
7	-27*	-11	2	-7	3	11	+14
9	-27*	-15	-5		-17		**

*Noise level obscures IM level.
**Insufficient data for comparison.

3.5 CONCLUSIONS AND RECOMMENDATIONS

Measurements of intermodulation interference aboard BLUE RIDGE resulted in the following:

a. Measurements of particular IM products strongly indicate that under certain conditions generally low levels of topside-generated interference will give way to much higher levels generated within one of the ship's 2-6MHz transmitting antenna systems. Levels attributable to topside sources average 29dB/μV for third-order products; seventh and higher order products are on the order of 1μV or less, and can be reasonably considered unimportant. Conversely, levels attributable to the antenna system are 23dB higher for the third-order product; the highest order of significance is not known, but it is surely greater than the seventh. Therefore, it is recommended that a program to locate and remove nonlinearities in the antenna system be undertaken.

b. The attempt to measure overall shipboard self-interference over a wide hf frequency range while transmitting with nine transmitters did not yield useful data. The primary reason was the change in propagation conditions which occurred during the measurements. Increases in signal strength from remote stations confused the results. On the other hand, observations of uhf noise during the same test were successful. UHF noise increased 2dB when nine hf transmitters were on the air.

c. Comparison of the self-generated hf interference characteristics of BLUE RIDGE and MOUNT WHITNEY shows a distinct advantage in favor of MOUNT WHITNEY. Her topside-generated levels average 13dB less than those of BLUE RIDGE. In addition, MOUNT WHITNEY did not indicate any interference generation by the transmitting antenna system. On the other hand, vhf levels aboard the two ships were found to be equal.

SECTION 4

BLUE RIDGE UHF TOPSIDE IM INTERFERENCE SURVEY

4.1 BACKGROUND

As stated in the preceding section, the entire project of measuring shipboard intermodulation interference aboard BLUE RIDGE included measurements at hf, vhf, and uhf. The hf and vhf results were presented in section 3. This testing also indicated significant sources of interference in the ship's uhf coaxial cabling; since similar cabling techniques may be used in many installations in the Fleet, the uhf results were selected for separate reporting.

Aside from the intermodulation measurements that were made, two principal interference generators the RG-331/U connectors and the PHASOR 90 power divider were examined. The results of these studies are also reported here.

4.2 IM INTERFERENCE TESTS

A series of diagnostic tests was performed to isolate the principal interference generators. The concept of these tests envisaged two phases. In the first phase, one complete PHASOR 90 transmitting system located in BLUE RIDGE's uhf radio compartment 1 would be subjected to a "Closed" system test wherein the four antennas of the antenna array would be temporarily disconnected and replaced by four linear dummy loads (LDL's) connected at the outputs of the rf power divider which is a part of the system. First-phase results would show the intrinsic intermodulation-generation property of the installed transmitting equipments. In the second phase, the antenna cables would be reconnected and the IM measurements repeated. If the results of the first phase were sufficiently low as compared to the results of the second phase, the conclusion could be safely drawn that the major IM interference source(s) were beyond the power divider in the direction of transmitter power flow.

The measurement system used for these uhf IM interference tests is shown in figure 4.1. Referring to this block diagram, the procedures followed and the results obtained for each of the diagnostic tests are discussed below.

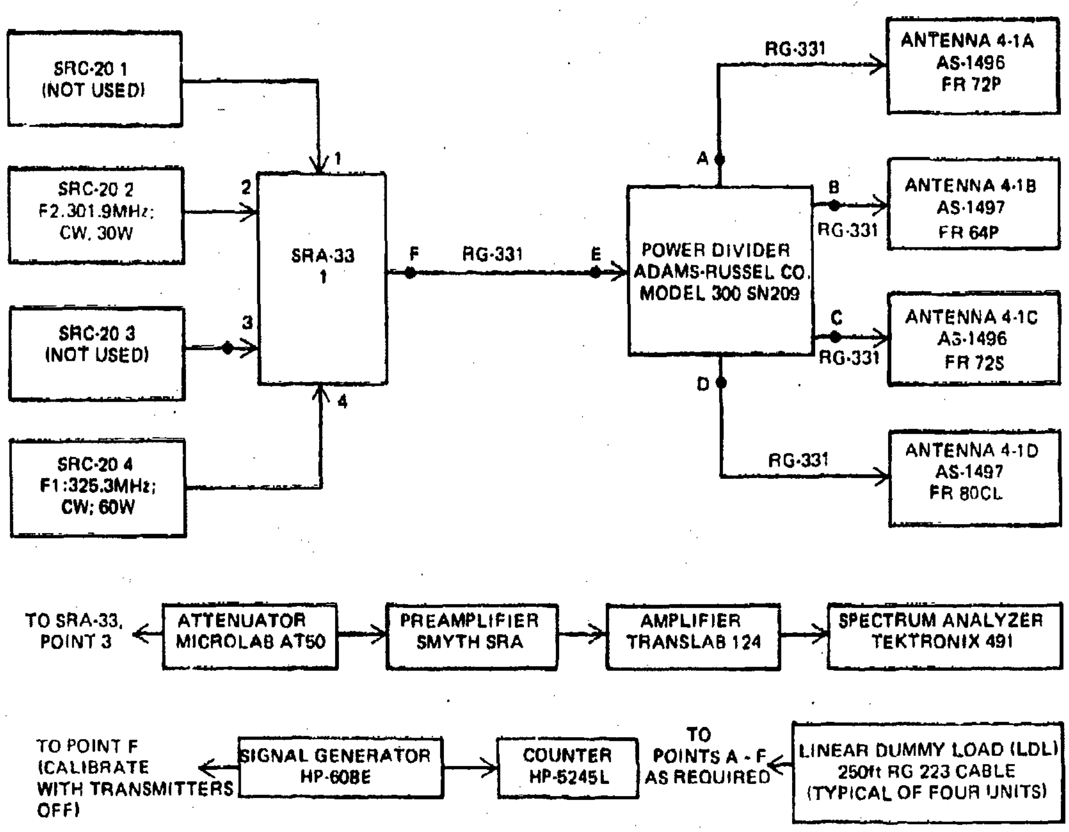


Figure 4.1. BLUE RIDGE uhf IM interference measurement system.

4.2.1 TEST A

Beginning with the initial first-phase measurement, the LDL coaxial cable connections at points A, B, C, and D and the receiver input at point 3 were made. The measurement receiver and section 3 of the SRA-33 were tuned as a system to the third-order intermodulation product frequency 2F1-F2 (348.7MHz). The measured level of the received IM product at this frequency was 60dB/μV, and was obtained when and only when both transmitters were keyed. This high level prompted a trial at a much-higher-order product, so receiver system tuning was adjusted to a 22nd-order product 12F1-10F2 (369.8MHz). The measured level was -3dB/μV. A third measurement at the fifth-order product 3F1-2F2 (372.1MHz) yielded 30dB/μV. At this time, it was decided to investigate specific possible sources within the transmitting system.

4.2.2 TEST B

One of the LDL's was removed from the power divider output and connected to the far end of the RG-331 cable leading from the multicoupler (point E). Repetition of the measurement at 372.1MHz produced the same level, which showed that the power divider was not the principal source. However, in the process of changing connections, it was noted that metal filings were present in the coaxial fitting on the RG-331. These particles were removed, but the properties of the fitting were still suspect. Accordingly, the connector was gently wobbled by hand while observing the rfi level. The wobbling action produced large variations in the observed level. This suggested complete removal of the RG-331 cable and its connectors from the system, and the LDL connection at F was made, placing the LDL directly at the output of the SRA-33. Under these latter conditions, the level of the samé fifth-order product dropped to approximately -10dB/μV. Accordingly, a length of RG-214 was substituted for the RG-331. With the LDL at the far end of the RF-214, the observed level was -5dB/μV. Thus, the RG-331 cable assembly was shown to be the principal source of nonlinear action.

At this point, the measurement receiving system was returned to the third-order intermodulation product frequency to obtain a stronger working signal. At this frequency, 348.7MHz, the level with the LDL at the far end of the RG-214 cable (point E) was 3dB/μV.

4.2.3 TEST C

The conditions of the initial test were reestablished by connecting the RG-214 to the power divider and replacing the LDL at the power divider output connector (point A). Under these conditions, the power divider produced a level of 26dB/μV. Thus, the level at 348.7MHz was reduced 34dB below the original level (when the RG-331 cable assembly was used). However, the power divider was also shown to be a lesser source of nonlinear action, since its inclusion in the system under test caused a 23dB increase in third-order product level.

4.2.4 TEST D

Since nothing could be done to modify the intrinsic rfi generation of the power divider, it was decided to substitute the antennas for the dummy loads in an attempt to observe topside-generated levels. This was done in step-wise fashion by first measuring the third-order level (348.7MHz) with one antenna and three LDL's, then two antennas and two LDL's, etc., until all four antennas were connected. With only antenna 4-1A connected, the level was 52dB/μV; with antennas 4-1A and 4-1B, the level was 68dB/μV; with 4-1A, 4-1B, and 4-1C, it was 64dB/μV; with all four antennas, the level was 60dB/μV. However, these levels were not believed due to topside generation. Since the antenna cables were also RG-331's, their connections were suspect. Grasping the four closely spaced cables with the hand and gently pushing back and forth produced variation in intermodulation product level and occasional bursts of broadband noise. This procedure was followed at several IM product frequencies; the results are given in table 4.1.

TABLE 4.1. IM LEVELS PRODUCED WHILE WOBBLING RG-331 ANTENNA CABLES.

IM Function (Order)	Frequency, MHz	IM Level, dB/μV Min	IM Level, dB/μV Max
2F1-F2(3)	348.7	60	80
3F1-2F2(5)	372.1	24	40
12F2-10F1(22)	369.7	3	5
25F2-22F1(47)	390.0	-3	8

An inspection of the installed connectors and cables indicated the most probable cause of the interference generation. Two types of connectors were found to be used on the RG-331 (Prodelin) cable, one manufactured by Phelps-Dodge and the other by Prodelin. Several of these connectors' locking nuts were only lightly tightened, and one connector was free to slip along the outside of the RG-331 outer aluminum conductor. The inspection was extended to other uhf and vhf installations both in uhf radio compartment 1 and in BLUE RIDGE's other equipment compartments. Use of this type of hardware is standard throughout the ship in installations operating at these frequencies. As a result, the decision was made to terminate uhf rfi testing and devote the remainder of the at-sea test period to other areas of interest within the scope of the overall task assignment.

4.3 RG-331 CONNECTOR DESIGN STUDY

Upon departing BLUE RIDGE, a short sample of RG-331 and one of each type connector were obtained. These were used, together with manufacturers' cross-section drawings and specifications, to obtain a better understanding of exactly how the connectors are designed and how they are supposed to be installed. At the conclusion of this brief study, the following technical opinions were formed:

a. In both types of connector, the electrical connections depend on mechanical pressure instead of an electrical bond. Pressure connections are subject to nonlinear contact resistance buildup due to vibration and/or chemical action over a period of time.

b. In both types of connector, mechanical pressure is applied through jamming nuts which appear subject to loosening under vibration.

c. RG-331 cable has a specified minimum bend radius of 5 inches. Lesser bend radii were formed in some places in the BLUE RIDGE installation, although accurate measurements were not made. Such bad practices should be avoided.

4.4 POWER DIVIDER EXAMINATION

One of the PHASOR 90 power divider assemblies was loaned to NELC by BLUE RIDGE for study. Upon close examination, it was found that the rf connectors on this assembly are modified type UG-30 D/U's. This type of connector was determined some time ago to be a source of intermodulation interference. It is a double-female, hermetically sealed device. The hermetic seal is obtained by forming the coaxial center conductor of kovar, or a similar alloy, which matches the thermal coefficient of the glass insulating bead that supports it. Unfortunately, alloys of this type are ferromagnetic. Therefore, when used in high-current-density, multifrequency applications, such as this case, IM interference is generated.

It should be pointed out that the power divider was designed even earlier than the discovery of the nonlinear property of the UG-30 D/U. Also, of this series, only the UG-30/U is linear; all other versions are nonlinear, including the latest modification, which is the UG-30 E/U. Attempts to obtain the UG-30/U from Navy supply have not been successful; however, it is available commercially.

4.5 DISCUSSION

It can be expected that the effect of the two types of nonlinearities found here on the quality of uhf voice communications will be quite variable. Reception of messages at some frequencies may be blocked from time to time by very strong low-order intermodulation interference. A considerably larger number of receive frequencies will coincide with high-order IM interference having much lower amplitude. The latter will have the effect of reducing the range at which effective communications can be maintained instead of the blocking effect of the lower order. The interference situation will be very dynamic. As the number of channels being used for transmission increases, the chance of IM interference of order 47 or less will increase at a very high exponential rate for the remaining channels being used to receive. Another source of variability is ship vibration. This will vary the condition of each junction-type nonlinearity, causing wide variation of IM product amplitudes and intermittent broadband noise bursts, which can occur with only one transmitter operating.

In a more academic sense, these data are something of a technical milestone; the measurement of the 47th-order intermodulation product is the highest order identified in a shipboard test to date. An interesting relationship is that the 47th-order level was of the same order of magnitude as the level of the 22nd. This may imply that after a certain order number is exceeded say order 9 choosing a somewhat higher order may not necessarily produce a significantly lower level when a truly efficient, natural nonlinearity is operating.

4.6 CONCLUSIONS AND RECOMMENDATIONS

a. High levels of intermodulation generation within the uhf transmitting system were found to mask topside-generated levels. Therefore, any effort to reduce rfi at uhf should first be expended on the transmitting systems rather than on topside areas.

b. Two types of interference generators were found in the transmitting systems. The most important type is nonlinear junctions formed in attaching coaxial connectors to RG-331 cable. This type causes (1) very high levels of low-order intermodulation products; (2) surprisingly high IM orders of much lower, but still significant, amplitude, and (3) intermittent bursts of broadband noise. The second type of generator is the ferromagnetic center pins of connectors used in the PHASOR 90 power divider assembly. This type is less important because IM levels are much lower and noise bursts are not generated by this mechanism. It is recommended that both types of generators be eliminated from the systems, with first priority being given to the RG-331 cable connectors.

SECTION 5

LABORATORY TESTS OF UHF TOPSIDE IM INTERFERENCE FROM BLUE RIDGE CONNECTORS

5.1 BACKGROUND

Section 4 gave results of uhf measurements aboard BLUE RIDGE which isolated sources of uhf intermodulation interference in the ship's uhf transmitting systems. The sources were determined to be rf connectors on RG-331 (Prodelin) coaxial cable and the uhf power divider in PHASOR 90 communication systems. In this section, the results of laboratory tests made at NELC of these two types of interference sources are given, together with recommended methods for correcting the difficulties.

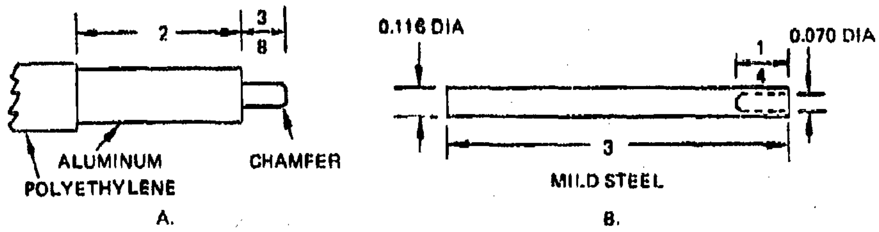
5.2 RG-331/U TESTS

Two different type-N male connectors are used to terminate the RG-331/U coaxial cables (Prodelin catalog number 54-500, Spirofoam) in the BLUE RIDGE installation. Most connectors are Prodelin catalog number 76-580(4) (Spirolok), but a few are Phelps-Dodge catalog number FX12-50 NM (Taperlok). The Phelps-Dodge connectors were found to be loose or finger-tight either because of incompatibility with the Prodelin version of RG-331/U cable or incorrect installation. The first interference tests were made on three short lengths of Prodelin's RG-331/U terminated with the Spirolok connectors at each end.

One pair of connectors was installed according to the Prodelin instructions. The second connector pair was given modified treatment of the coaxial cable inner conductor so more conductor could be inserted in the male pin sleeve; also, a simple tool was made to remove the pin from the rest of the connector (without destroying pin stability in the completed connector). (The tool used and procedures for its use are described in figure 5.1.) Connector-pin mating was then observable during the process of joining coax cable and connector. The third connector set was treated with the same modification as the second set, but careful soft soldering of the male pin and coax inner conductor ensured a good electrical connection. (Attempts at using room temperature Eccobond 57C solder were very disappointing.)

Tests of rfi generation on the first set confirmed the situation found in the uhf system aboard BLUE RIDGE. The rfi signal level dropped drastically with the modified treatment of the male pin in the second set. The lowest interference level of all three tests came with the soft-soldered male pin in the third set. These measurement results are summarized in table 5.1.

Both the Prodelin and Phelps-Dodge claims for simple, fast connector installation without special tools are correct, but they ignore the fact that the price for speed and simplicity is the increased probability these connectors will cause system-generated rfi from intermodulation sources built into the connectors. Comparison of the male pin sleeves in the two types of connectors show that Prodelin's design is superior to Phelps-Dodge. The latter is vulnerable to splaying of the sleeve by the coax conductor during installation, resulting in a very poor pin-to-coax-inner-conductor contact.



NOTE: ALL DIMENSIONS IN INCHES (NOT TO SCALE)

1. Prepare RG-331 cable as shown in A. (Center conductor is 1/8in. longer than Prodelin specification.)
2. Place Prodelin connector catalog number 76-580(4) on flat surface with male center pin pointing up.
3. Slip driver tool B. over center pin. Tap with hammer, driving out center pin.
4. Place connector backnut and gripping sleeve over outer cable conductor.
5. Firmly bottom socket in back of connector center pin on cable center conductor. Soft solder in place.

   CAUTION: Use minimum heat and minimum solder for good joint.

6. Slip outer connector shell over cable end, observing proper center pin fit. Tighten assembly. USE WRENCHES.

   NOTE: Other cable and connector sizes are expected to require different dimensions. Adjust to suit.

Figure 5.1. Tool and procedures for modification of Prodelin connector installation.

TABLE 5.1. SUMMARY OF LABORATORY TESTS OF RG-331/U CONNECTORS AND PHASOR 90 POWER DIVIDER AS SOURCES OF SYSTEM-GENERATED RFI.

UHF power sources: TED-3 and T-431/URT transmitters

All dummy loads in closed-loop setup are linear (long lengths of RG-58/U coax)

Both transmitters and receivers filtered. F1 = 243MHz, F2 = 256MHz

IM test frequency, 2F2-F1 = 269MHz

Test	IM Level, dBm
Test setup residual IM level	-120
Check out with single UG-30D/U	-96
Standard Prodelin connectors	-50
Modified connectors, no solder	-100
Modified connectors, soldered	-120
Unmodified PHASOR 90 power divider	-40
Connectors replaced with UG-30/U's	-47
UG-30/U's with steel lockwashers removed	-107

5.3 POWER DIVIDER TESTS

The other source of uhf-system rfi reported was the PHASOR 90 four-way power divider. It was also investigated under the same controlled test conditions applied to the RG-331/U connectors. As pointed out in section 4, this power divider is constructed with five slightly modified UG-30D/U, double female, type-N panel connectors. This type of hermetically sealed connector, along with other hermetic connectors for other coax cable sizes, has a long history of being a consistent source of system-generated intermodulation interference due to the nonlinearity of the ferromagnetic pin which runs through the glass seal. The Navy supply system could not provide UG-30/U connectors (note the absence of any letter following the number 30) which are known to be linear because they are not hermetically sealed. Fortunately, they were available from a local commercial distributor. The original, modified UG-30D/U's were replaced carefully with similarly modified UG-30/U's.

RFI tests before and after replacement proved that intermodulation signal power with the new connectors dropped to 20% of the original level. However, the interference was still unacceptably high. Only when the five steel lockwashers were removed from the new connectors did the rfi drop to near the test setup residual level; these washers were the same ones used with the original UG-30D/U connectors. Therefore, although the UG-30D/U was proved once again to be a potent source of system generated rfi, the unexpected "lockwasher effect" is an excellent example of an obscure rfi source. The approximate interference power level relationship of the two sources is that the UG-30D/U's contribution is four times greater than that from the lockwashers. Both levels are very significant. Again, measured levels are summarized in table 5.1.

Plans were made to solve the PHASOR 90 power divider problem without modification by permanently magnetizing the ferromagnetic pin in each of the five UG-30D/U connectors. This approach is based on previous experiments where application of a strong magnetic field to the pin completely removed the nonlinear characteristic and thus the source of intermodulation. The strong magnetic bias made the ferromagnetic conductor linear as long as the field was present. Continued applications of the field built up a cumulative effect where the residual magnetism retained in the pin lowered appreciably the level of IM signal generated with the magnetic field removed. It was hoped that the pins could be magnetized enough to remove the nonlinearity permanently. The technique is feasible, but it was impossible within the available time frame to devise a source of strong magnetism tailored to the needs of the UG-30D/U connectors. Obviously, the ferromagnetic pin must be parallel to the magnetic lines of force; the distance between pole faces of a magnetron magnet was too narrow to accommodate the length of the connector. However, such a simple latent solution to the power divider problem justifies additional consideration of the permanent magnetic pin concept.

5.4 SUMMARY AND RECOMMENDATIONS

In summary, it was found that interference generated in the Prodelin connectors and the power dividers could be very substantially reduced. The following recommendations result:

a. Do not use Phelps-Dodge catalog number FX12-50 NM (Taperlok) connectors with RG-331 coaxial cable (Prodelin catalog number 54-500, Spirofoam).

b. Install Prodelin catalog number 76-580(4) connectors on RG-331 cable in accordance with the modified procedures given in figure 5.1.

c. Remove UG-30D/U connectors and internal steel lockwashers from PHASOR 90 power dividers. Substitute UG-30/U connectors; do not use UG-30 series models A through E. UG-30/U's are not available from Navy stock, but can be purchased commercially.

SECTION 6

IWO JIMA TOPSIDE IM INTERFERENCE SURVEY

6.1 BACKGROUND AND OBJECTIVES

Studies of topside intermodulation interference aboard USS IWO JIMA have been previously performed by NELC.[4] This experience showed clearly that a severe topside IM interference problem existed aboard the ship. Consequently, the formal task assignment under which the work reported here was performed called for locating the principal sources of interference and providing design guidance for their removal. This guidance would be extended to all ships of the LPH class. More specifically, the project order (P.O. 1-1029) specified four tasks to be performed relative to the IWO JIMA:

a. Make measurements and determine hf, vhf, and uhf IM levels.

b. Determine the contribution of the hf antenna's mechanical design to the interference problem reported by IWO JIMA by making diagnostic changes and tests of topside antenna and rigging.

c. Determine if the interference problem is a general class problem.

d. Provide design guidance to rectify the interference conditions.

The overall topside IM interference generation characteristic of the IWO JIMA was not to be measured. Results of such measurements are useful only to the extent that rigorous documentation of the severity of topside-generated interference is needed.

6.2 APPROACH

To arrive at the goal of reducing topside interference, it was necessary to make intermodulation measurements in the frequency bands specified in the task assignment. These measurements were directed at either sectionalizing areas of the ship or evaluating specific potential topside interference contributors (probing). The results form the basis for the design guidance needed.

Determination of whether interference problems similar to those aboard IWO JIMA could be expected aboard ships of the same class did not require repetition of the measurement program aboard an additional ship. Sufficient data were obtained aboard USS TRIPOLI (LPH 10)[5] before the recent modernization of her communications suit to confirm similarity of interference conditions.

In addition to the quantitative testing, other broadband transmitting antennas aboard IWO JIMA were visually inspected. The results of these inspections are also reported.

[4]Naval Electronics Laboratory Center CONFIDENTIAL Letter Serial 2100-0216 to COMPHIBPAC, subject: *Radio Frequency Interference (RFI) on USS IWO JIMA (LPH 2)*, 3 September 1970

[5]NELC CONFIDENTIAL Letter Serial 2100-044 to NAVSHIPS and NAVSEC, subject: *Fleet Support Task, USS TRIPOLI (LPH 10) HF Communications*, 7 April 1970

6.3 TEST SITE CONDITIONS

The ambient conditions which had the most effect on the interference survey were (a) the ship's mooring, (b) ambient electromagnetic noise, and (c) the weather.

The ship was moored on the north side of pier 8, U.S. Naval Station, San Diego, in the berth farthest from shore. Across the pier, to starboard, a destroyer-type vessel was moored. Since the distance between the ships was only about 100 feet, some contamination of overall received levels due to the presence of the other ship was probable. On the other hand, clearance to port was good, there being more than 100 yards of open water.

Ambient electromagnetic noise generated by industrial activity in the Naval Station had to be avoided. The intent was to use the weakest signals possible; high industrial noise would degrade reception of weak signals. Past experience in making measurements in this locality had shown sharp daily reductions in ambient noise beginning at about 1600 hours local time and extending through the weekends. Topside tests were, therefore, made during these periods of minimum industrial noise.

Wet weather has been observed to temporarily reduce topside-generated intermodulation levels on many occasions. Apparently, the residue of sea salt being dissolved in the rainwater in many topside junctions serves to effectively reduce nonlinear action. During the first two days of the IWO JIMA tests, there was a series of heavy rain showers which kept the ship wet. Thus, the interference observed during this period was due to the most easily excited nonlinearities that were also least affected by the wet weather. Consequently, interference generation by ferromagnetic materials in high current portions of transmitting systems would tend to become the dominant factor. Later in the test period, the ship dried out and IM signals became higher in amplitude and produced the more typical "hashy" receive audio output.

6.4 SECTIONALIZING TESTS

6.4.1 MEASUREMENT TECHNIQUE

The technique used in the sectionalizing tests aboard IWO JIMA was derived from a method proposed in reference 1. That paper dealt with several aspects of high-order intermodulation interference which had been shown (in reference 4) to exist aboard IWO JIMA. The method proposed in reference 1 is for determining the most significant topside IM interference contributors aboard a ship. It is based on the fact that, when the power of the transmitter fundamental frequencies applied to a nonlinear circuit element is changed by a given amount, the amplitude of the high-order products is changed by a greater amount than the amplitude of the low-order products. The proposed test method contemplates exciting the topside surfaces of a ship with two transmissions of just enough power to make a high-order IM product barely detectable on the ship's receiving antennas. With this situation established, previously developed topside nonlinearity location techniques would be used to find a source of interference energy topside. Temporarily interrupting the action of the located nonlinearity, thereby reducing the level of interference at the receiving antenna to a point below the level of detectability, would confirm the located nonlinearity as the "worst" source.

Successive applications of the technique, using higher and higher transmitter powers, would establish an ordered list of topside sources. It should be noted that this technique tends to minimize the contamination of results due to the mooring problems discussed in section 6.3.

6.4.2 INSTRUMENTATION/PROCEDURES AND RESULTS

Practical application of the proposed technique imposed some modifications. For example, the choice of transmitting antenna location was of importance since this factor would influence fundamental frequency current distribution over the topside surfaces. Therefore, two widely different transmitting antenna combinations were selected. One combination consisted of the deck edge whips, antennas 3-9 and 4-2 in figure 6.1. The other combination consisted of radiating the same two signals from antenna 2-5 mounted atop the island superstructure. Antenna 2-5 is the one referred to in part b of the task assignment (section 6.1). Since it was desired that the only change between the two cases would be the change in antenna geometry, the transmitting equipments were arranged as shown in figures 6.2 and 6.3. Using these two transmitting system arrangements, in turn, intermodulation products were received using the ship's 2-30MHz receiving antennas and the equipment shown in figure 6.4. The transmitting antenna arrangement which yielded the highest order of IM product with sufficient amplitude to be detected was considered to be the most important in the overall interference situation.

This arrangement turned out to be that of the island antenna. Antenna 2-5 was, therefore, the antenna used during the probing tests of specific potential topside contributors. Other sectionalizing tests were also conducted to divide the interference problem by frequency band and receiving location. The sequence of these tests is described next.

TEST A – DECK EDGE TRANSMITTING ANTENNA TESTS. As indicated in figure 6.2, NELC antenna matching networks were necessary to assure that the deck edge transmitting system was not radiating intermodulation frequencies at sufficiently high levels to degrade accurate measurement of topside-generated interference. The NELC networks have no sliding or rolling contacts, and are fabricated of nonferromagnetic materials. Unfortunately, the two SRA-22 units are not so fabricated. This type of standard Navy whip antenna tuner has been shown to be a strong generator of interference in closed-system laboratory tests.[6] On the other hand, the NELC networks are like the SRA-22 in that neither type supplies sufficient filtering to assure that interaction between the two transmitters would not occur. This interaction could supply sufficient IM interference energy to reduce accuracy in measuring topside levels. Thus, the additional filtering shown in figure 6.2 was necessary.

[6] IIT Research Institute, Contract No. N00123-69-C-0584, *Study of Nonlinear Properties of the AN/SRA-22 Antenna Coupler*, Final Report.

NOTES.
1. "(T)" INDICATES TRANSMITTING ANTENNA; "(R)" INDICATES RECEIVING ANTENNA.
2. CALLOUTS OF ANTENNAS USED IN TESTS ARE UNDERLINED.

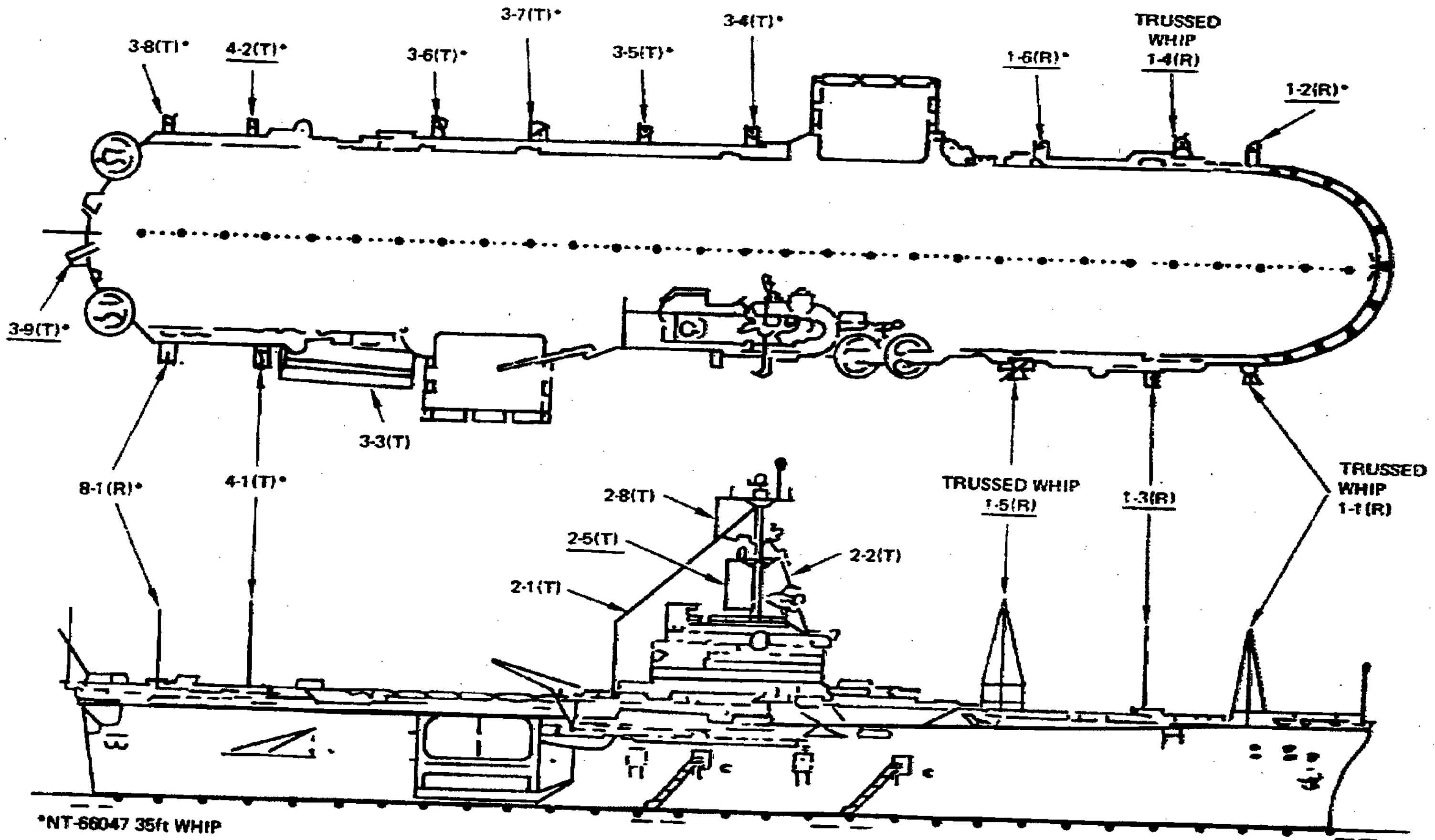


Figure 6.1. IWO JIMA 2-30MHz antennas.

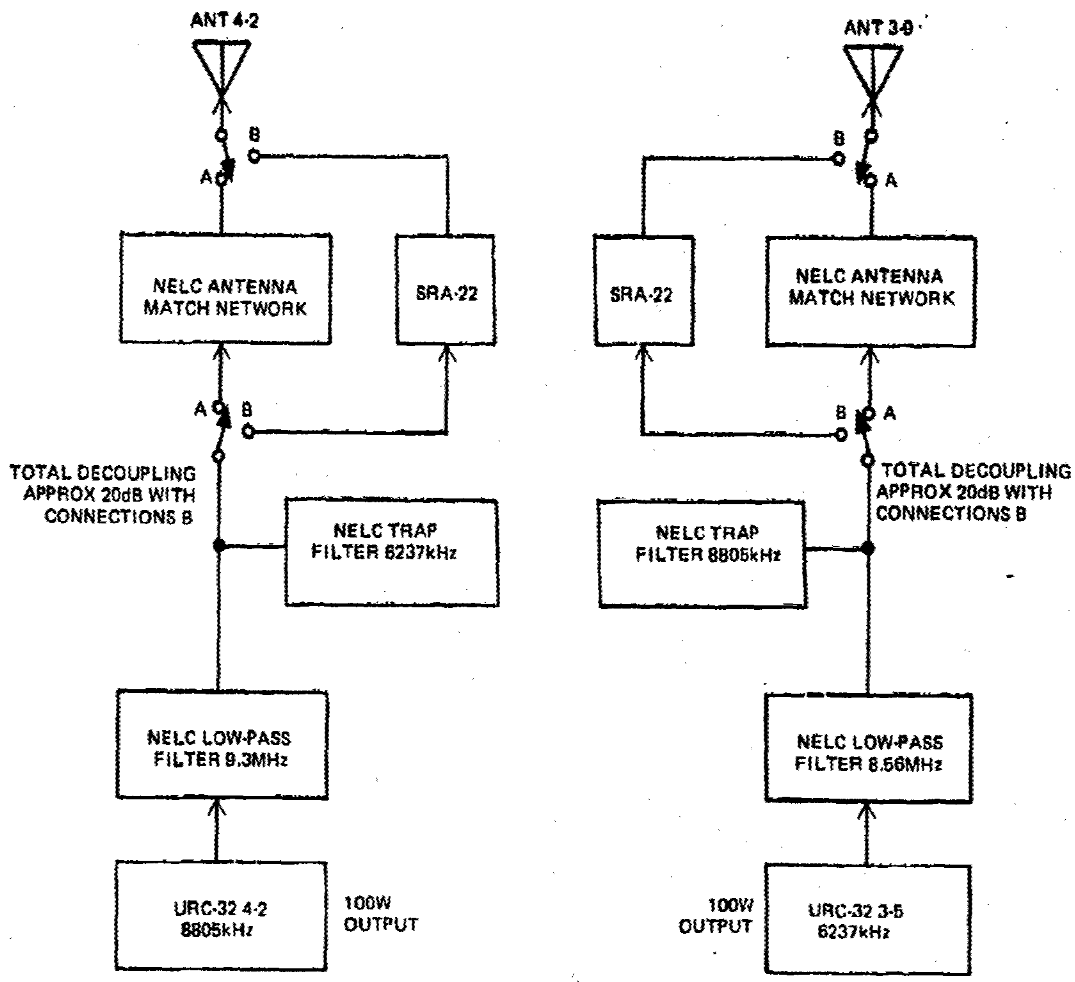


Figure 6.2. IWO JIMA rfi test transmitters radiating from deck edge whips.

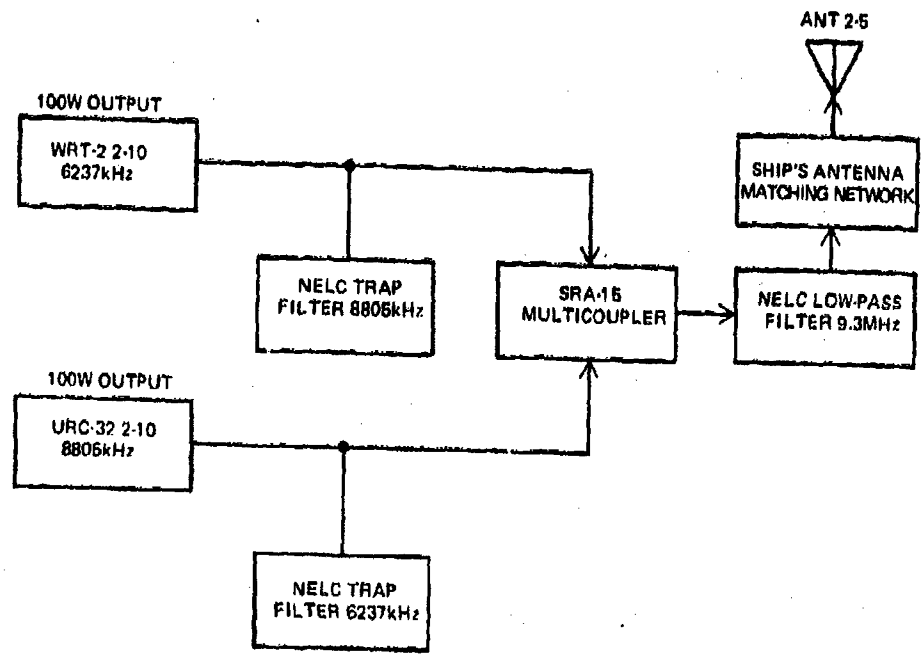


Figure 6.3. IWO JIMA rfi test transmitters radiating from island antenna.

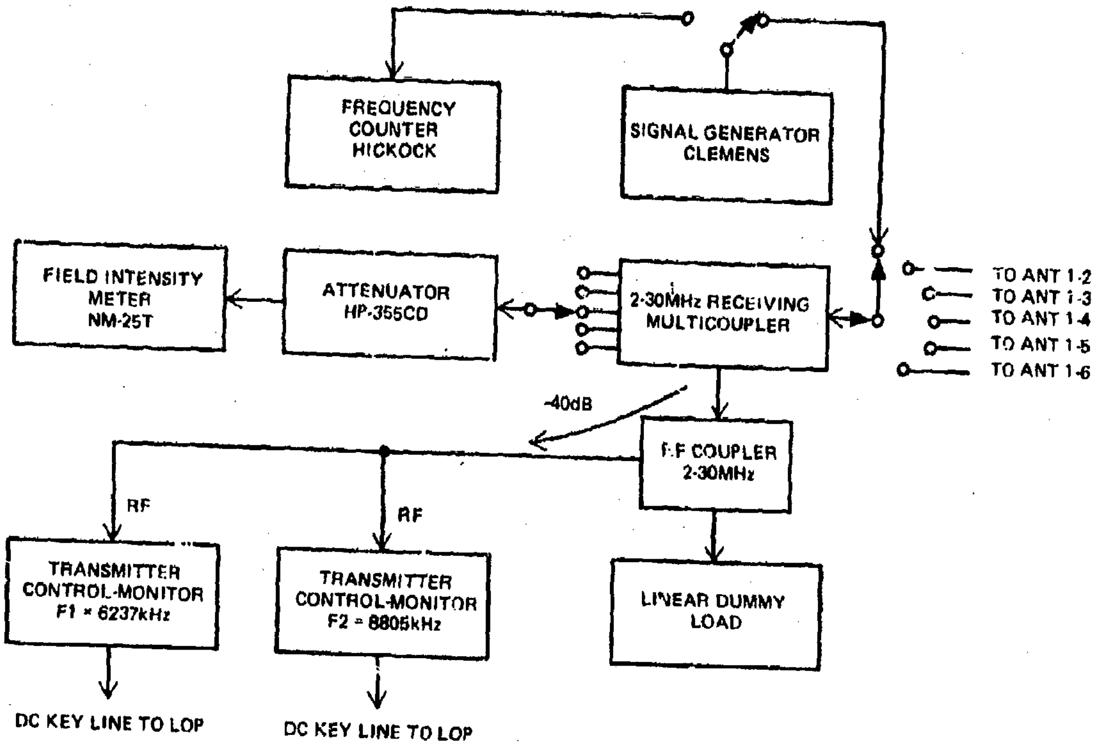


Figure 6.4. IWO JIMA 2-30MHz rfi test receiving equipment.

Advantage was taken of wet weather suppressing topside intermodulation. Measurements made under these conditions are much more indicative of IM generation in transmitting systems. A set of IM interference data was obtained with connections "A" of figure 6.2. Then, the connections "B" were made, both SRA-22's were adjusted in accordance with standard procedure, and a second set of data was recorded. Since these were the only changes, the differences can be attributed to use of the SRA-22's. The results are summarized in table 6.1.

TABLE 6.1. IWO JIMA RECEIVED HF TOPSIDE IM LEVELS WHEN RADIATING FROM DECK EDGE WHIPS (OCTOBER 1971).

TRANSMITTING SYSTEM

F1 = 6237kHz at 100W antenna 3-9
F2 = 8805kHz at 100W antenna 4-2

RECEIVED LEVELS

IM Order	IM Function	IM Frequency, kHz	IM Level (Average per Antenna), dB/μV										IM Level (Overall Average), dB/μV		
			Ant 1-2		Ant 1-3		Ant 1-4		Ant 1-5		Ant 1-6				
			A	B	A	B	A	B	A	B	A	B	A	B	Notes
3	2F1-F2	3669	45	50	38	38	49	51	49	45	40	44	44	47	
5	3F2-2F1	13941	32	28	22	25	22	29	16	19	21	35	23	27	
7	4F2-3F1	16509	(4)	9	(-4)	8		7		8	(7)	17		10	1
9	7F1-2F2	26049	(-13)	(-11)	(-10)	-7		14	(-15)	(-16)	-	-6		-9	2
13	7F2-6F1	24213	(-10)	(-8)		(-10)		(-14)	(-15)	(-15)		-3			2
14	6F2-8F1	2934					(8)								1

Levels A: NELC antenna matching networks used (ref. fig. 6.2).
Levels B: SRA-22 antenna tuners used (ref. fig. 6.2).
Note 1: Levels in parentheses are ambient QRM; IM not detected.
Note 2: Levels in parentheses are ambient noise; IM not detected.

TEST B ISLAND TRANSMITTING ANTENNA TESTS. To avoid the possibility of weather conditions changing and thereby affecting the comparison of data taken with the two different transmitting antenna arrangements, data were recorded using the island antenna as soon as possible after completing the deck edge tests. However, it was not practical to substitute an antenna matching network known to be free of nonlinear materials and construction, as indicated in figure 6.3. Thus, the data obtained using antenna 2-5, which are summarized in table 6.2, must be considered to include intermodulation energy contributions by the matching network.

TABLE 6.2. IWO JIMA RECEIVED HF TOPSIDE IM LEVELS WHEN RADIATING FROM ISLAND ANTENNA (OCTOBER 1971).

TRANSMITTING SYSTEM

F1=6237kHz; F2=8805kHz; 100W cw each input to cable leading to antenna 2-5 with filtering as in figure 6.3.

RECEIVED LEVELS

IM Order	IM Function MF1+NF2	IM Frequency, kHz	IM Level (Average per Antenna), dB/μV Ant 1-2	Ant 1-3	Ant 1-4	Ant 1-5	Ant 1-6	IM Level (Overall Average), dB/μV
5	3F2-2F1	13941	30	37	44	37	46	39
7	4F2-3F1	16509	35	37	33	37	35	35
11	6F2-5F1	21645	2	18	15	19	25	16
13	7F2-6F1	24213	0	-1	0	-2	10	1
17*	8F2-9F1	14307	37	22	27	24	27	27
19**	13F1-6F2	28251		10**				
19***	10F2-9F1	31917	-9	-8	-12	-11	-2	-7

*Levels are not due solely to IM product. Minimum of three transmitters involved. Antenna 1-4 had TTY sound, all others had distorted commercial broadcast audio.

**Level given is ambient noise. However, IM could be heard using BFO, although meter reading did not increase when transmitters were keyed.

***Reception at this frequency required use of NELC 30-76MHz bandpass filter in lieu of filtering shown in figure 6.4. IM rose approximately 5dB above ambient noise when transmitters were keyed.

Note: All levels recorded were very steady. Heavy rain showers occurred during test.

TESTS C AND D VHF TESTS. Two situations were used to produce measurable intermodulation interference at vhf. First, interference was observed using the receiving system shown in figure 6.5 while transmitting at hf from antenna 2-5 as before. The resulting data are given in table 6.3. Second, two vhf transmitters were used, as shown in table 6.4 along with the resulting data.

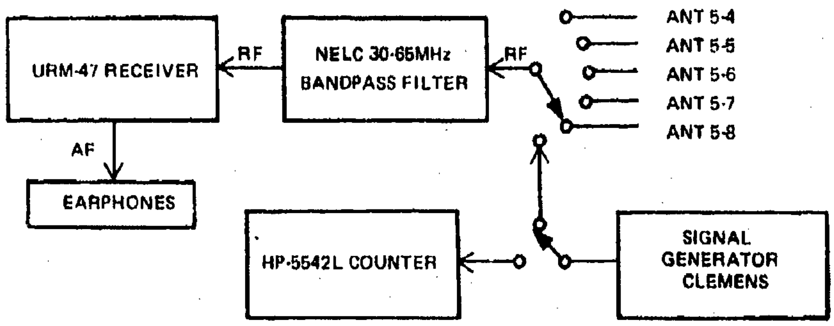


Figure 6.5. IWO JIMA vhf rfi test receiving equipment.

TABLE 6.3. IWO JIMA RECEIVED VHF TOPSIDE IM LEVELS WHEN RADIATING AT HF FROM ISLAND ANTENNA (OCTOBER 1971).

TRANSMITTING SYSTEM

F1=6237kHz; F2=8805kHz; 100W cw each, radiated from antenna 2-5 with filtering as in figure 6.3.

RECEIVED LEVELS

IM Order	IM Function MF1-NF2	IM Frequency, kHz	IM Level (Average per Antenna), dB/μV Ant 5-4	Ant 5-5	Ant 5-6	Ant 5-7	Ant 5-8	IM Level (Overall Average), dB/μV
5	0F1+5F2	44025	[illegible]	39	32	39	35	37
6	3F1+3F2	45126	1		22	21	24	17
7	6F1+F2	46227	19	13	26	23	27	22
7	-2F1+5F2	31551	31	30	39	24	25	30
8	8F1+0F2	49896	15	18	30	15	14	18
10	9F1-F2	47328	7	11	16	7	10	10
13	11F1-2F2	50997	0	10	14	3	9	7
15	12F1-3F2	48429	6	6	11	10	6	8
18	14F1-4F2	52098	5	7	16	14		10

TABLE 6.4. IWO JIMA RECEIVED VHF TOPSIDE IM LEVELS WHEN TRANSMITTING AT VHF (OCTOBER 1971).

TRANSMITTING SYSTEM

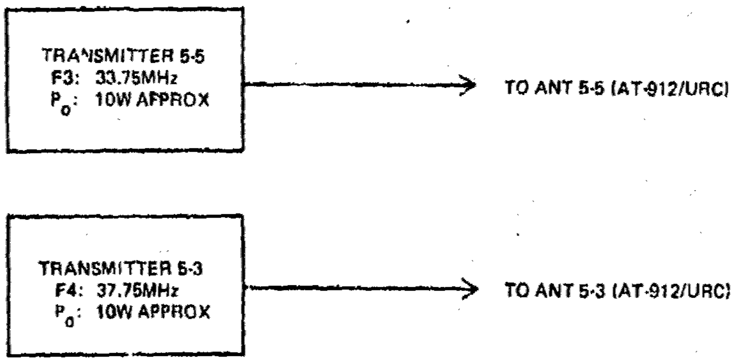


TABLE 6.4 (Continued)

RECEIVED LEVELS

IM Order	IM Function MF3+NF4	IM Frequency, MHz	IM Level (Average per Antenna), dB/μV Ant 5-4	Ant 5-6	Ant 5-7	Ant 5-8	IM Level (Overall Average), dB/μV
3	2F3-F4	29.75*	41	40	20	12	28*
3	-F3+2F4	41.75	24	44	22	35	31
5	3F3-2F4	25.75	9	11	12	25	14
5	-2F3+3F4	45.75	5	24	19	20	17
7	-3F3+4F4	49.75	3	14	3	9	7
39	21F3-18F4	29.25	**	**	**	**	

*When receiving at this frequency, keying transmitter 5-3 only caused clear reception of "rock" music at an average level of 16dB/μV. Keying transmitter 5-5 only caused clear reception of a soap commercial at an average level of 10dB/μV. Keying both together gave average cw levels indicated, except on antenna 5-8, where a garbled mixture of the two sounds could be heard. Audio level was much weaker with both transmitters keyed while receiving on antenna 5-8; not audible on other antennas.

**IM was detectable in earphones, but too weak to measure with meter.

NOTE: Receiving system as in figure 6.5.

TESTS E AND F – UHF TESTS. Two situations were used to measure intermodulation interference at uhf also. First, two uhf transmitters and a sensitive receiving system were multicoupled to the same load(s), as shown in figure 6.6. The measurement results are given in table 6.5. The second situation combined one uhf transmitter with an hf transmitter. The uhf transmitter was at 256MHz (F6), 85 watts. The hf transmitter was at 8805kHz (F2), 400 watts cw radiating from antenna 2-5, and connected as shown in figure 6.3. The receiver was the same as shown in figure 6.6. These IM interference measurement results are given in table 6.6.

TABLE 6.5. IWO JIMA TOPSIDE IM LEVELS WHEN TRANSMITTING AND RECEIVING AT UHF ON THE SAME ANTENNA (OCTOBER 1971).

IM Order	IM Function MF5+NF6	IM Frequency, MHz	IM Level (Average), dB/μV Ant 6-1	Ant 6-6	Dummy
3	2F6-F5	269	71	-	30
5	3F6-2F5	282	45		-
7	4F6-3F5	295	42		
9	5F6-4F5	308	23		
11	6F6-5F5	321	21		
13	7F6-6F5	334	20	43*	

*Reading taken as sample comparison. Lack of time did not permit further measurements.

NOTE: Equipment connected as in figure 6.6.

TABLE 6.6. IWO JIMA RECEIVED UHF TOPSIDE IM LEVELS WHEN TRANSMITTING AT HF AND UHF (OCTOBER 1971).

TRANSMITTING SYSTEM

F2: 8,805kHz, 400W cw, with filtering as in figure 6.3, radiated from antenna 2-5.
F6: 256MHz, 85W cw, radiated from antenna 6-1 as in figure 6.6.

RECEIVED LEVELS

IM Order	IM Function MF2+NF6	IM Frequency, MHz	IM Level,* dB/μV
3	2F6+F6	273.610	6**
3	2F2+F6	273.610	26***
3	F6-2F2	238.390	24
2	F6+F2	264.805	20
2	F6-F2	247.195	20

Higher orders not detectable

*IM products received on antenna 6-1 with receiving equipment as in figure 6.6.
**Average level, initial condition
***After shaking ant 2-5, this average level obtained

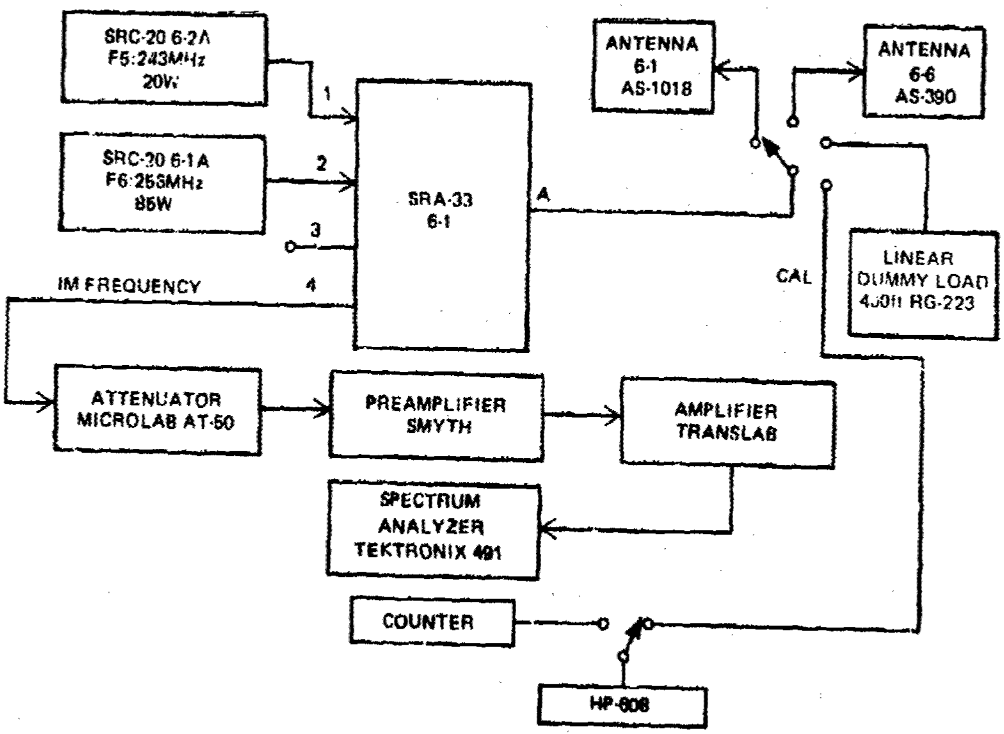


Figure 6.6. IWO JIMA uhf IM interference measurement system.

6.4.3 DISCUSSION

TEST A TRANSMITTING WITH DECK EDGE ANTENNAS. As shown in table 6.1, the highest order intermodulation product detectable when using the NELC matching networks (connections "A") was order 5. When the SRA-22 was used, the highest detectable order was 9. Thus, the order and amplitudes of the several orders were both increased. Clearly, the SRA-22 deleteriously affected the overall IM interference levels. The shipboard check of the SRA-22 was prompted by closed-system tests of this type whip antenna coupler in the laboratory. Spot checks of the TN-342 and URA-38 equipments indicate that these other types would yield roughly similar effects when tested aboard ship in a like manner. Thus, elimination of IM interference generation in shipboard whip antenna tuners is not likely to be a simple matter of substituting one coupler type for another.

TEST B TRANSMITTING WITH ISLAND ANTENNA. Comparing the results of table 6.2 with those of table 6.1, it is seen that, when the same intermodulation products were measured, even higher levels were obtained than when the SRA-22 was used with the deck edge antennas. Also, the island antenna yielded detectable levels at the 19th order as opposed to a maximum of ninth order for the deck edge antennas with the SRA-22. Therefore, the island antenna (2-5) is the most important in the overall topside-interference situation aboard IWO JIMA.

However, there is more information in the data than just the foregoing conclusion. Consider the levels obtained when the 17th order was measured. They are higher than the levels at both order 13 and order 19. Also, since both transmitters were cw, an intermodulation product of the two transmitted fundamentals should act very much like a cw signal in the test receiver. A distinct single tone should appear and disappear as the receiver BFO is switched on and off. However, other sounds were heard whether or not the BFO was used. The unexpectedly high measured level and the unexpected audio associated with the IM product serve to show that the observed signal is not due to intermodulation between the two test emissions alone. This violates the basic premise of the experiment, and, therefore, these 17th-order data may not be treated in a manner like the other data. Addition of the third (at least) transmitter signal in the intermodulation situation creates a high risk that some low-order IM product between the three emissions can lie within the measurement receiver bandwidth. This could explain both the audio and the high measured level at this frequency. On the other hand, the extraneous transmission was undoubtedly being radiated from a point some distance from the ship. Hence, the field strength at the ship would be quite small as compared to the own-ship test transmitter emissions. Low field strength implies that the nonlinear elements topside responsible for the received IM level were closely associated with an efficient antenna. Candidates would be transmitting antenna 2-5 and the receiving antennas.

TEST C — RECEIVING VHF IM WITH HF TRANSMISSIONS. At a first glance at table 6.3, it would appear that only the 18th order was detected rather than the 19th order (table 6.2) when receiving at hf. However, the vhf antennas used to receive the interference are very closely spaced around the transmitting antenna (2-5) at the 07 level on the island, while the hf receiving antennas are mounted around the edge of the flight deck, forward. Therefore, the vhf antennas are in much stronger transmitter fundamental frequency fields, which would tend to indicate that even higher orders than the 19th should be detectable. Also, there are some peculiarities in the measured amplitudes. Consider the amplitudes obtained when measuring progressively higher intermodulation orders. Levels from the 10th through the 18th are essentially constant: this should not be so. Levels should decrease as the order increases.

The foregoing anomalies can be explained by carefully considering the frequency characteristics of the intermodulation spectrum generated between the two particular transmitter fundamental frequencies in use during these tests and the selectivity of the URM-47 field intensity meter which was used to receive components of that spectrum. Mathematical analysis shows that all the IM product frequencies which can be obtained between the two transmitter fundamentals 6237kHz and 8805kHz occur at 3 kHz intervals across the electromagnetic spectrum. (Since this document is concerned with a specific application, only the results of the analysis will be given; proof of the analytic method will be deferred to a later report.) Fortunately, the 3kHz spacing does not mean that every such frequency will be of sufficient amplitude to be detected. It does mean, however, that, when measuring levels of higher order IM products using the URM-47, great care must be used.

It must be assured that the order of the intermodulation product frequency the URM-47 is intended to measure is in fact the lowest order IM product having its frequency within the receiver bandwidth. Since the URM-47 has a 130kHz bandwidth, it can theoretically accept 43 IM product frequencies (in this case) at a time. This means there must be an upper limit of IM order which can accurately be measured with this receiver. Further analysis shows that this limit is at order 18, for these particular transmitter fundamentals and for the receiving band 30-76MHz. It is for this reason that the data of table 6.3 are truncated at order 18. Note that this does not necessarily mean that all orders higher than 18 are undetectable.

Indeed, it can be reasonably hypothesized, on the basis of the measured data, that orders higher than 18 are detectable. If, say, 10 of the frequencies lying in the receiver bandwidth are detectable, the URM-47 will respond to them all very much as it would to white noise. That is, the indicated level would be proportional to the total power in all the 10 intermodulation products. So long as the frequencies of the lower order products are avoided, no single IM frequency will have a large amount of power when compared to the total of all the power of other IM frequencies in the receiver bandwidth. Thus, only relatively small changes in the indicated level would occur as the center frequency of the receiver was shifted about.

TEST D – RECEIVING VHF IM WITH VHF TRANSMISSIONS. On comparing the measurements and equipment status of this test with those of test C, it is seen that there are significant differences. Transmitters were at much higher frequencies and much lower power, and their signals were radiated from separate antennas. Also, no special measures were taken to prevent the fundamental signal of one transmitter from reaching the final amplifier of the other transmitter. The filters required were not available at NELC at the time of the tests. Thus, it is possible that some of the observed IM interference was generated in the transmitters themselves.

Because of the change in transmitter frequencies, the URM-47 had sufficient selectivity to resolve the components of the intermodulation spectrum in this test. When these two vhf transmitter fundamental frequencies (33.75MHz and 37.75MHz) are analyzed in like manner as the hf fundamentals, it is found that the minimum theoretical IM product frequency separation is 0.25MHz. This is almost twice the URM-47 bandwidth (0.13MHz).

The results of this test are fairly straightforward shipboard intermodulation interference data. The audio effects observed when receiving at 29.75MHz are similar to audio effects observed in test B. That is, signals from off-ship transmitters were mixing with own-ship transmissions, causing significant IM interference levels. However, the remote transmitter frequencies, the orders of the IM products, and the location of the interference-generating nonlinearities are all unknown. All that is really known is that there is a serious source of interference. Considering the amplitudes received, almost everything in the area near the receiving antennas (including these same antennas) is suspect.

TEST E – RECEIVING UHF IM WITH UHF TRANSMISSIONS. The equipment arrangement used in this test is given in figure 6.6, as mentioned above. Since the minimum theoretical intermodulation frequency spacing between IM products of the two transmitter fundamentals (243MHz and 256MHz) is 1MHz, the receiving equipment can easily resolve the higher order products. This is because the spectrum analyzer can be operated with frequency resolution as fine as 1kHz.

As shown in table 6.5, when measuring the third-order intermodulation product with the SRA-33 terminated in the linear dummy load, a level of 30dB/μV was obtained. This was disappointingly high compared to results of similar measurements made on like design equipments aboard other ships. However, when antenna 6-1 was used, the level rose to 71dB/μV. Therefore, the major portion of the interference could be ascribed to sources outside the transmitting equipments. Measurements were continued at successively higher IM products using antenna 6-1 as the transmitter load until order 13 was reached, yielding 20dB/μV. At this frequency, antenna 6-6 was used for comparison, yielding the much higher level of 43dB/μV. At this point, the test using only uhf transmitters was terminated. The ship availability period was drawing to an end, and it was felt the remaining time could be used to better advantage than determining the highest order product between the uhf transmitters.

TEST F – RECEIVING UHF IM WITH ONE UHF AND ONE HF TRANSMISSION. The goal of this test was simply to determine whether intermodulation products generated by such an arrangement could be detected. If so, steps could be taken to show whether the hf antenna itself was involved in the generation of the detected IM. Accordingly, a length of dry nylon line was attached to the hf transmitting antenna (2-5) at the 07 level so that it could be safely swung with high rf power applied. Otherwise, the method of operating the equipments and the measured results are those summarized in table 6.6. Note that the power of the hf transmitter was increased to 400 watts for this test.

The levels received at the third-order product, 273.610MHz, are very interesting and significant. The initial "as found" level was 6dB/μV, average. After the antenna was swung, the average level increased to 26dB/μV. Therefore, some junction-type of nonlinearity within antenna 2-5 contributed in a major way to the interference level received on antenna 6-1. This means that, at the uhf transmitter fundamental frequency, sufficient energy was present in the junction to cause the interference. Decoupling between the two antennas can safely be estimated as 30dB. Therefore, the uhf power in antenna 2-5 can be estimated as a few milliwatts. Of course, the generated uhf IM product had to be radiated back to antenna 6-1 in order that the test receiver could detect it, so the total of antenna and decoupling losses had to be overcome. Thus, the level in antenna 2-5 was much higher than that received. What is probably more significant, however, is the apparently wideband operation of the interference source. Who can say just what frequency this action stops? For example, antenna 2-5 is illuminated by the SPS-40 radar, which operates at frequencies somewhat above 400MHz. It is entirely reasonable to assume that significant interference is caused by intermodulation between the powerful transmitted radar pulse currents and hf transmitter fundamental currents flowing in antenna 2-5. Such IM interference would be in addition to the radar spectrum "skirt" interference, making an already bad situation much worse.

Returning to table 6.6, it is surprising that orders higher than 3 were not detected. The noise level of the receiving system is equivalent to less than -23dB/μV when measured at point A in figure 6.6 and when 1kHz bandwidth is used. This is approximately 50dB below the measured level of the third-order products. Therefore, good measurements through at least the seventh order should have been possible. Probably, the junction source of interference in the antenna was disturbed by some small mechanical force such as the breeze. This could have caused it to cease acting, just as shaking caused it to start.

6.5 PROBING TESTS

The probing tests were designed to give more detailed information about sources of topside-generated intermodulation interference than the previously described sectionalizing tests. Since the technical goals were different, considerably different procedures were used and different data resulted.

6.5.1 INSTRUMENTATION/PROCEDURES

The transmitting system used in these tests is given in figure 6.3. It was operated in locked-key mode, which was not true in the sectionalizing tests. On the other hand, two receiver systems were used. One receiver, hereafter called the reference receiver, was the equipment connected as in figure 6.5, except that only a single vhf antenna was used. The reference receiver was tuned to 52 098kHz, which is the frequency 14F1-4F2. The second receiver system is called the probing system, and is described in figure 6.7. This system was tuned to 28 251kHz (13F1-6F2). Battery operation of the probing receiver is essential since it must be carried about topside. The loop antenna is used to probe specific, suspected intermodulation generators at the tuned frequency. Having found some physical feature of the ship which is carrying the IM current, it is necessary to prove that the signal from that source is in fact detectable by the ship's receivers. That is the function of the reference receiver. The detected average level using this reference is observed while the suspected interference source is mechanically manipulated, if a junction is p[illegible] offender is suspected. This changes the properties of the junction and, thus, the IM level generated therein. If the average level at the reference receiver changes in synchronism, a significant source has been located. Naturally, due regard must be given to personnel safety, as was done during the probing test of antenna 2-5, with power applied. In that case, junctions were disturbed with a long dielectric rod.

When probing at the flight deck level, the above procedure was varied somewhat as a matter of convenience. A suspected significant source was found with the probe, as before. Next, the probe antenna was used to sense the intermodulation current flowing in a nearby receiving antenna, such as antenna 1-4. Then, the suspect junction was disturbed, and the same decision rule applied.

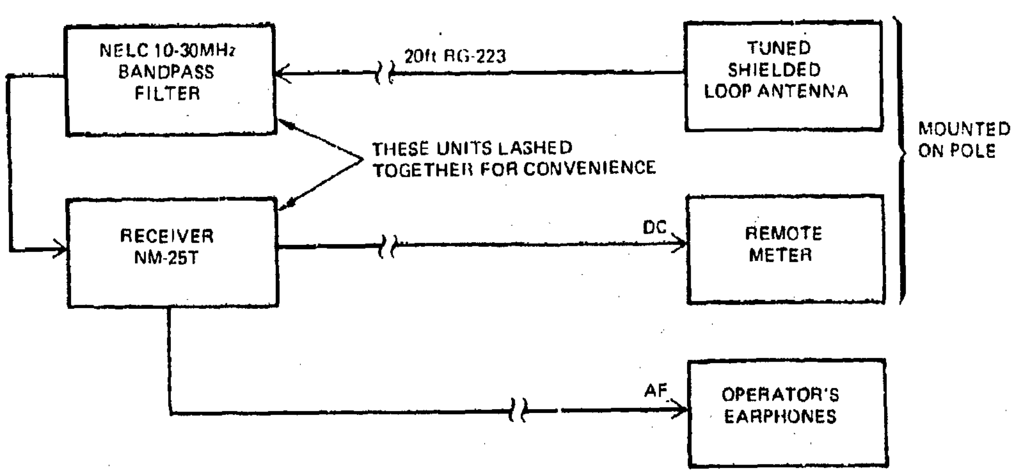


Figure 6.7. IWO JIMA hf topside IM source locating equipment.

6.5.2 RESULTS

On the basis of the sectionalizing test results, the probing tests were begun with an investigation of antenna 2-5 at the 07 level of the island superstructure. It was quickly found that no single junction within the antenna assembly could be called "the" source of interference. The reason for this is easily seen in figure 6.8. The upper photograph (A) shows a general view of the antenna looking forward toward the antenna feedpoint, which is shown in the lower center. Energy flows from this point to nine phosphor bronze wires which spread out to the large spreader bar that traverses the center foreground.

A.

B.

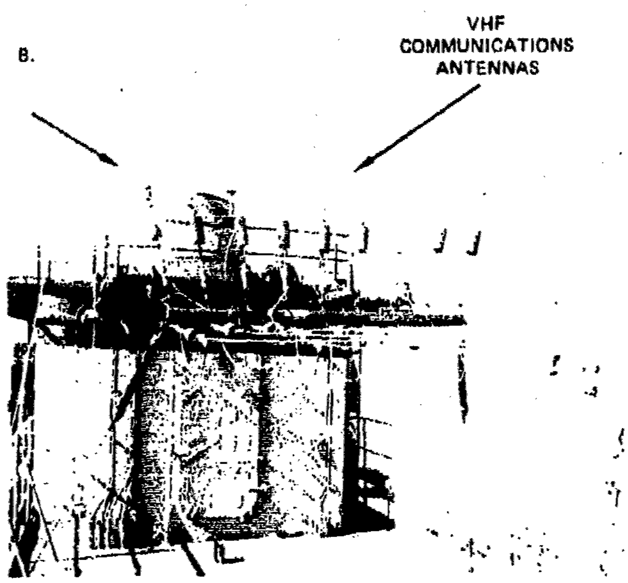
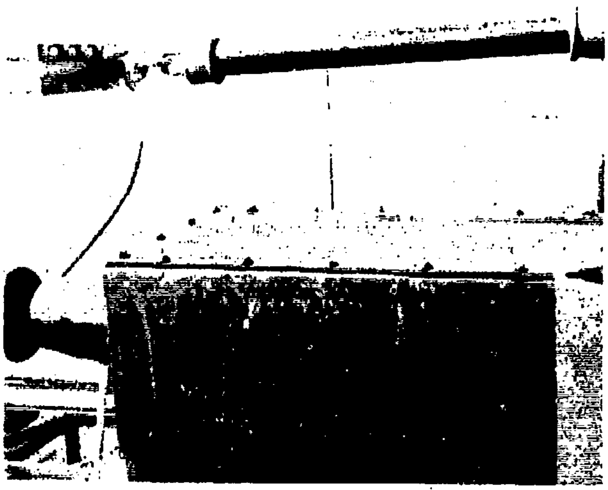


Figure 6.8. IWO JIMA antenna 2-5 showing multiplicity of springs, shackles, turnbuckles, etc. (A), and other closely located antennas (B).

Notice the multiplicity of springs, shackles, turnbuckles, etc., used to hold the assembly together. Almost every joint in the assembly yielded some sort of interference effect. Some yielded only bursts of broadband noise, while others also caused measurable changes in the average level of the intermodulation product at the reference receiver. The lower photograph (B) shows another view taken looking aft from a point just to starboard of the antenna feedpoint. The structure in the background supports several vhf communications antennas, which can be seen mounted around its upper edge. Some of these antennas are almost within arms' reach of antenna 2-5.

A.



B.

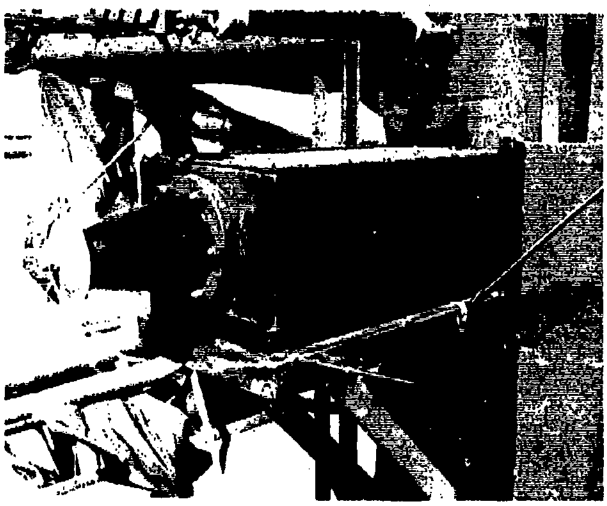


Figure 6.9. Feedpoint and matching network of IWO JIMA antenna 2-5 showing ferromagnetic steel feed block (A) and copper straps "grounding" steel case to steel support bracket (B).

Figure 6.9 shows two close-up views of the antenna impedance matching network. In the upper photograph (6.9A), the antenna feedpoint and its supporting strain insulator can be seen. Figure 6.10 shows two close-up views of the feedpoint hardware. Almost all the equipment in these four photographs is made of ferromagnetic steel. Exceptions are the antenna wires themselves, the feedwire, the insulators, and the copper straps (fig. 6.9B) which are used to "ground" the steel case of the matching network to its steel support bracket. It is believed the use of the ferromagnetic parts in the high current paths of the antenna yielded the very steady levels of intermodulation products observed in sectionalizing test B (table 6.2).

A.

B.

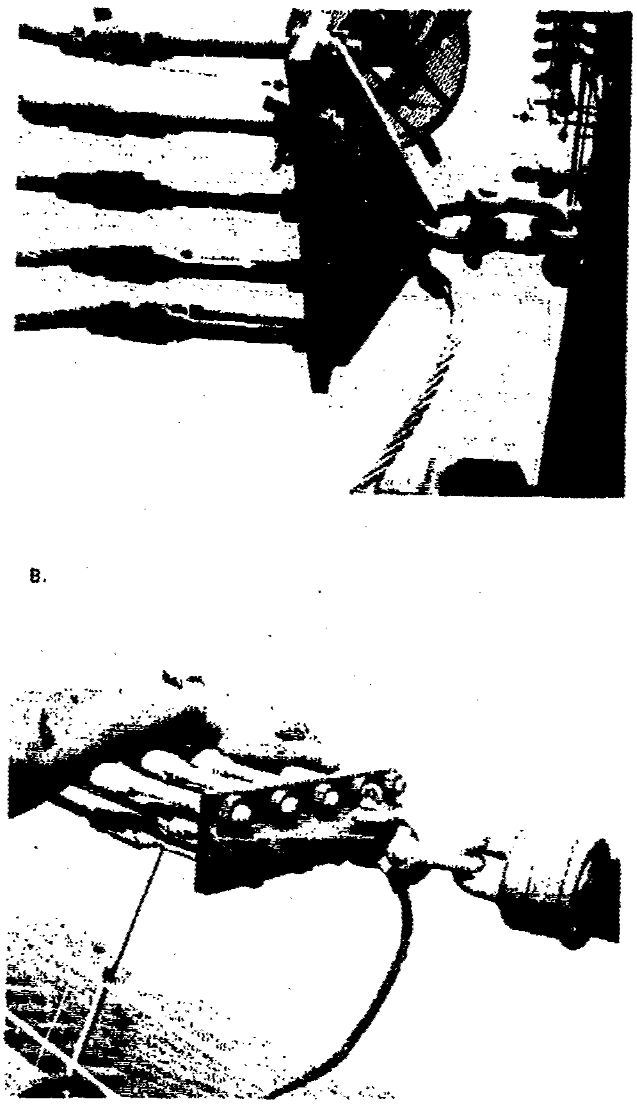


Figure 6.10. IWO JIMA antenna 2-5, feedpoint details.

Probing was extended to other items on the island. Two sources outside antenna 2-5 were found. One of these is shown in figure 6.11. In figure 6.11A, a protective waveguide cover touches the sharp edge of the waveguide. In figure 6.11B, the same aluminum cover is bolted to a steel support bracket.

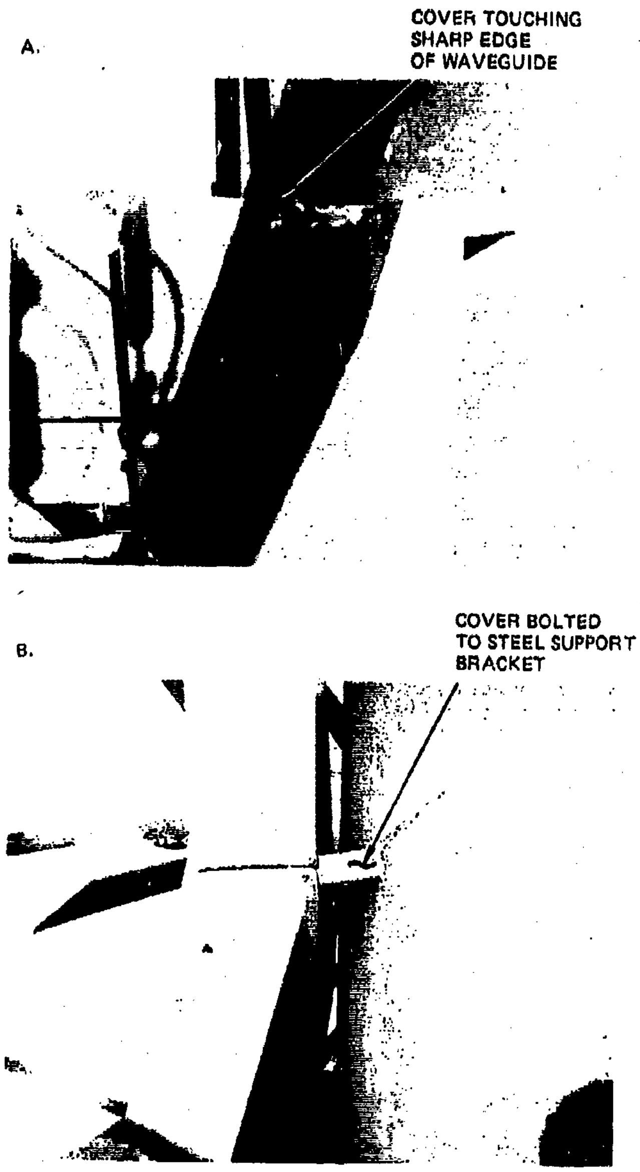
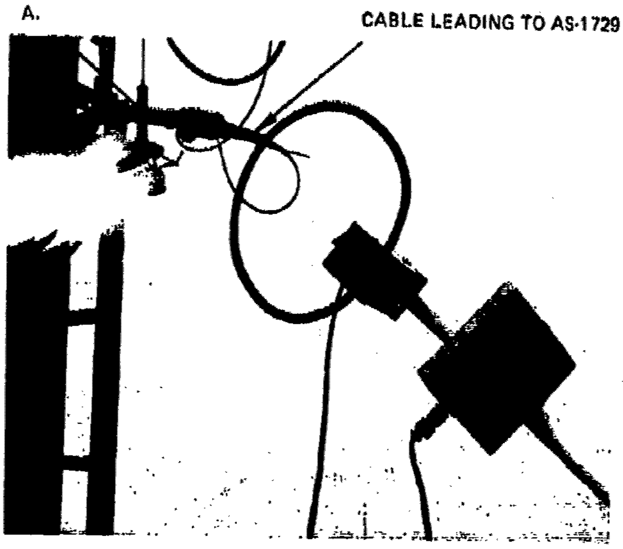


Figure 6.11. IWO JIMA topside IM source: protective aluminum waveguide cover.

A general view of this assembly is shown in figure 6.8A, just to the right of the antenna 2-5 matching network. The other source is really not a single thing, but a class of items. These are the vhf antennas, of which some samples are shown in figure 6.12. In 6.12A, the probe antenna senses the interference generated in the cable leading to an AS-1729. In 6.12B, a different type antenna is shown. The jointed counterpoise rods in this antenna are the sources. Note that the outboard counterpoise rod has lost its outer end.

A.



B.

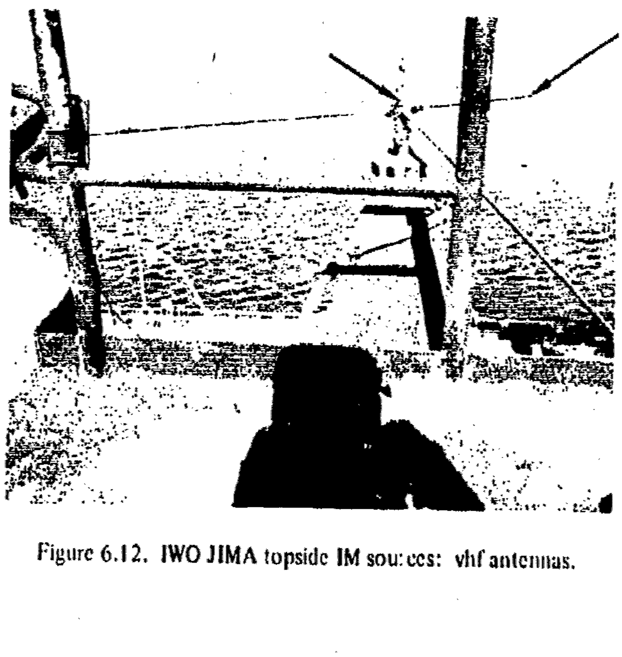
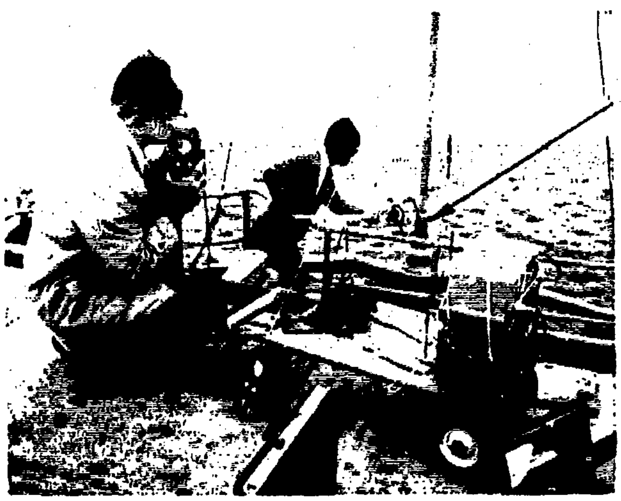


Figure 6.12. IWO JIMA topside IM sou:ces: vhf antennas.

After probing of the island was complete, the flight deck areas were investigated. Surprisingly, of all the many possibilities, only the two lifeline assemblies at the extreme fore and aft ends of the flight deck were found to be generators of high-order intermodulation. Figure 6.13A shows how the IM signal was sensed at the ship's receiving antenna, while figure 6.13B shows one set of lifeline junctions. There were several items which generated only bursts of noise detectable at the ship's receiving antennas when the items were shaken. These were the jackstaff and the flagstaff and several short, metallic ladders leading down from the flight deck to the peripheral gallery.

A.



B.

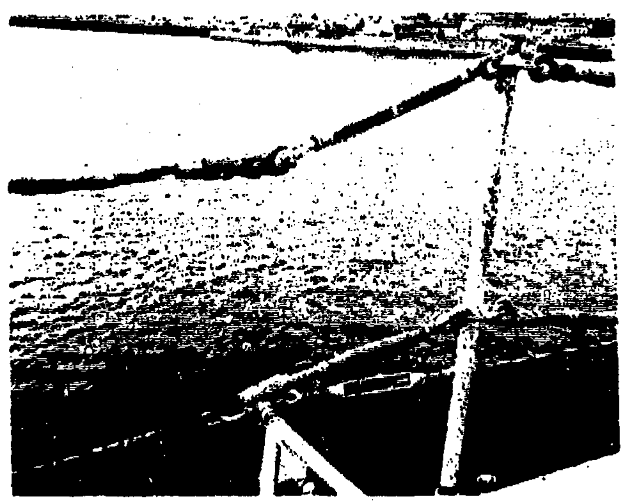
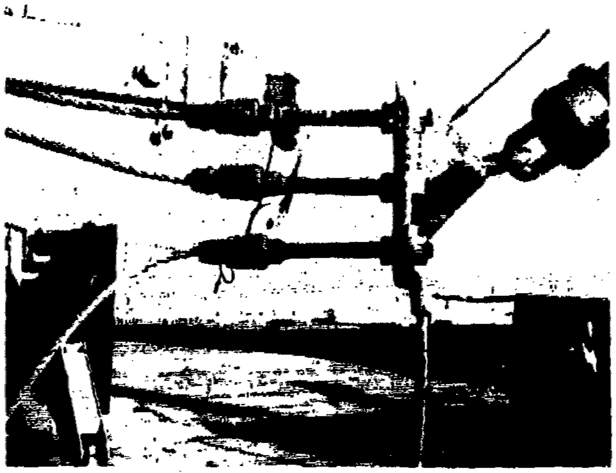


Figure 6.13. Evaluating IWO JIMA topside IM sources: lifeline assemblies on flight deck.

6.6 TOPSIDE INSPECTION

The probing tests concluded actual quantitative testing aboard IWO JIMA. However, the investigators were concerned that other broadband transmitting antennas aboard the ship would exhibit nonlinear properties similar to antenna 2-5. Antenna 2-8 (18-27MHz) was visually inspected using binoculars. Hardware similar to that of antenna 2-5 was used, and some parts were rusty, indicating use of ferromagnetic materials. Antenna 2-1 (2-6MHz) was given closer inspection since it was lowered to the flight deck one day for maintenance. Figure 6.14 shows two views of the ferromagnetic blocks used as the feedpoints of this antenna.

A.



B.

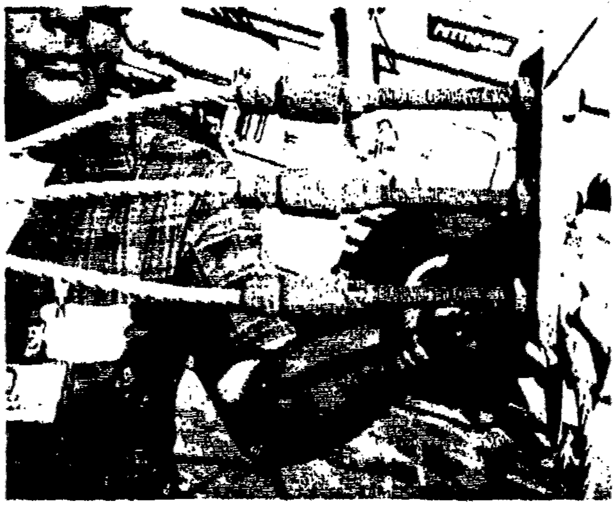


Figure 6.14. IWO JIMA antenna 2-1, feedpoint details.

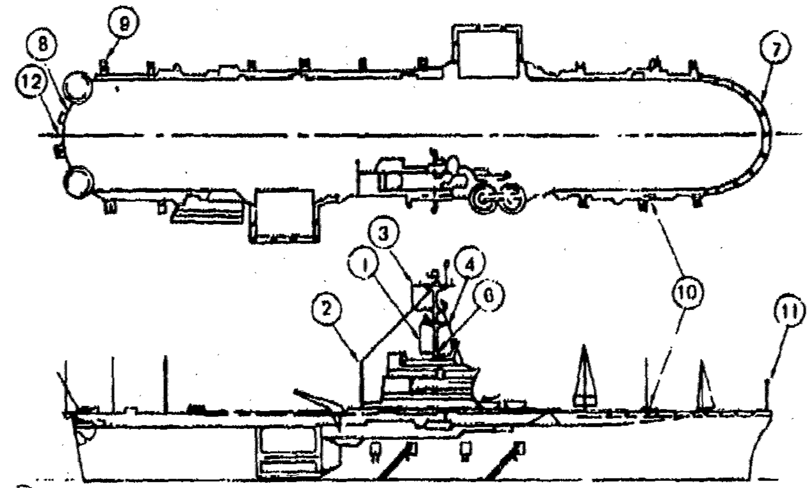
6.7 GUIDANCE

The communications suit aboard IWO JIMA is to be modernized. It is believed the result will be a suit very much like that of her sister ship USS TRIPOLI. TRIPOLI has three broadband hf receiving antennas each feeding the appropriate SRA-38, -39, -40 series receiving multicoupler. Broadband island transmitting antennas are fed by SRA-56, -57, -58 multicouplers. Shaped feed antennas (as opposed to the old-style folded fan) are used in the 6-30MHz range, while the twin-fan type is retained in the 2-6MHz band. At vhf, transceivers are protected from interacting with each other by use of SRA-60 multicouplers with broadband AS-2231 antennas. These design changes are based on sound engineering approaches to compatible operation of communications equipments aboard warships. They are essential. Unfortunately, they are not sufficient.

Sufficiency requires that generation of intermodulation interference in, say, the broadband circuitry of a transmitting system be suppressed. Linear operation of the signal combiner in the transmitting multicoupler, the coaxial cable, the antenna matching network, and the antenna itself is necessary. Powerful transmitter fundamental currents flow in these equipments. If non-linearities are present, high-level IM interference will be generated. Then, the carefully designed, highly efficient antenna will radiate the interference for detection by own-ship receivers. As the data of this document show, failure to achieve linear operation of a broadband transmitting antenna can produce significant interference levels over a band of frequencies much greater than the design bandwidth of the antenna. To avoid similar effects in the modernized transmitter system, the new antenna matching networks and the new antennas must not include the following: (a) loose joints or joints that can become loose after subjection to shock, vibration, and corrosive atmospheres; (b) ferromagnetic materials. Further, restriction of this guidance to just the hf transmitting systems would be erroneous. It should be applied to other bands, whether receiving or transmitting.

An example of this line of thinking is the AS-2231 vhf dipole. An antenna of this type is presently undergoing shock and vibration testing at NELC. It was visually inspected for possible nonlinear elements before those tests were begun. In the weatherproof box wherein the coaxial cable is connected to the antenna assembly, two hermetically sealed coaxial connectors were found: one was a UG-30E/U double female; the other was a UG-680/U panel connector. Since the box is only weatherproof, hermetically sealed connectors which have ferromagnetic center conductors are not required. They should be replaced with UG-30/U (note the absence of the letter suffix!) and UG-58A/U types. Unfortunately, the UG-30/U is not available from Navy supplies; it must be obtained from commercial sources.

It is believed that guidance given by NELC directed toward reduction of intermodulation interference aboard LPH-class ships should, at this time, be limited in scope. Tests were not carried out with the higher transmitter powers as described in section 6.4. The primary reason for this was that the "worst" source of interference (transmitting antenna 2-5) could not be temporarily eliminated so that many less important sources could be found. Thus, a minimum plan has been prepared which would eliminate the most important sources. It is believed this plan will achieve significant reduction of topside IM interference at reasonable cost. Figure 6.15 summarizes the essential features of this plan.



(5) TO BE INSTALLED IN MODERNIZATION

Figure 6.15. Minimum effective rfi reduction plan for amphibious assault ships based on tests aboard IWO JIMA.

ITEM	CATEGORY*	DESCRIPTION	ACTION REQUIRED
1	A	TRANSMIT ANTENNA	REPLACE WITH NEW DESIGN; NEW ANTENNA MUST NOT INCLUDE FERROMAGNETIC MATERIALS OR UNBONDED CONNECTIONS.
2	A	TRANSMIT ANTENNA	SEE ITEM 1
3	A	TRANSMIT ANTENNA	SEE ITEM 1
4	A	TRANSMIT ANTENNA	SEE ITEM 1
5	A	AS-2231	REPLACE UG-30E AND UG-680 WITH UG-30 AND UG-58A.
6	B	WAVEGUIDE COVER	MAKE NEW OF 1/16in STEEL, WELDED ASSEMBLY, TACK WELD TO SHIP
7	B	BOW LIFE LINE	REPLACE PER NAVSHIPS DWG 600-4413577 AND NAVSEC DWG 805-4543251
8	B	AFT LIFE LINE	SEE ITEM 7.
9	C	TYPICAL TRANSMIT WHIP SYSTEM	COMPLETE, BASIC REDESIGN OF HF TRANSMISSION LINE COMPONENTS. FILTER PROTECTION FOR TRANSMITTER REQUIRED· NO IMMEDIATE SOLUTION
10	D	TYPICAL DECK EDGE LADDER	TACK WELD, WHERE POSSIBLE, TO SHIP
11	D	JACKSTAFF	REPLACE WITH GLASS REINFORCED PLASTIC DESIGN
12	D	FLAGSTAFF	REPLACE WITH GLASS REINFORCED PLASTIC DESIGN

*CATEGORIES

A MAJOR SOURCE; GENERATES HIGH-LEVEL, HIGH-ORDER IM AND NOISE BURSTS; EFFECTIVE OVER WIDE FREQUENCY RANGE.

B PRIMARY SOURCE; SIMILAR TO A, BUT HAS EITHER LOWER LEVELS OR REDUCED BANDWIDTH.

C – SECONDARY SOURCE; SOURCE OF LOW-ORDER IM AT LOW TRANSMITTER POWER.

D POTENTIAL SOURCE (NOT A PROVEN SOURCE); AT LOW POWER, GENERATES DETECTABLE NOISE BURSTS ONLY; HIGHER TRANSMITTER POWER MAY CAUSE DETECTABLE IM GENERATION.

NOTE PLAN ASSUMES MODERNIZATION OF SHIPS' COMMUNICATIONS SUIT & ANTENNA ARRANGEMENT WILL BE DONE CONCURRENTLY.

6.8 CONCLUSIONS AND RECOMMENDATIONS

a. The objectives of the intermodulation interference measurements program aboard IWO JIMA have been achieved. Data were obtained which conclusively show that one broadband hf transmitting antenna is the most serious source of IM interference. Since the remaining broadband antennas were constructed using the same fabrication techniques or materials, guidance has been given whereby the same undesired performance characteristics can be avoided in the new, modernized antennas to be installed. In addition to the antennas, removal of several other sources of interference having somewhat less serious effects is recommended.

b. As a result of this program, the technique of using higher order intermodulation products to identify the most serious topside interference sources has been shown to be effective. Some improvements are needed, however, to speed the process so that the work can be done more economically. More theoretically, the method of analyzing IM frequency spectra has been extended so that several heretofore unexplained phenomena can now be predicted. This extended method is described in detail in reference 2.

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13. ABSTRACT

The results of measurements of intermodulation (IM) interference taken aboard USS MOUNT WHITNEY, USS BLUE RIDGE, and USS IWO JIMA are presented. In addition, the results of laboratory tests of connectors that were interference sources aboard BLUE RIDGE are reported.

IM interference levels measured aboard MOUNT WHITNEY were determined to be lower than those aboard USS FOX (DLG 33), which was previously considered to have the lowest topside-generated rfi levels among active Fleet warships.

Interference levels at hf and vhf on BLUE RIDGE were found to be higher than MOUNT WHITNEY levels but still lower than those on FOX.

UHF IM interference measurements taken aboard BLUE RIDGE indicated serious sources of interference in PHASOR 90 transmitting systems. Substituting connectors not having nonlinear material for the Prodelin cable connectors and in the PHASOR 90 power divider was proposed as a corrective measure.

By applying new measurement techniques, important sources of topside-generated interference were located and identified aboard IWO JIMA. A plan of minimum topside rfi control measures for LPH-class ships was devised which, while not reducing levels to those of FOX, will effect a major improvement at minimum cost.

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